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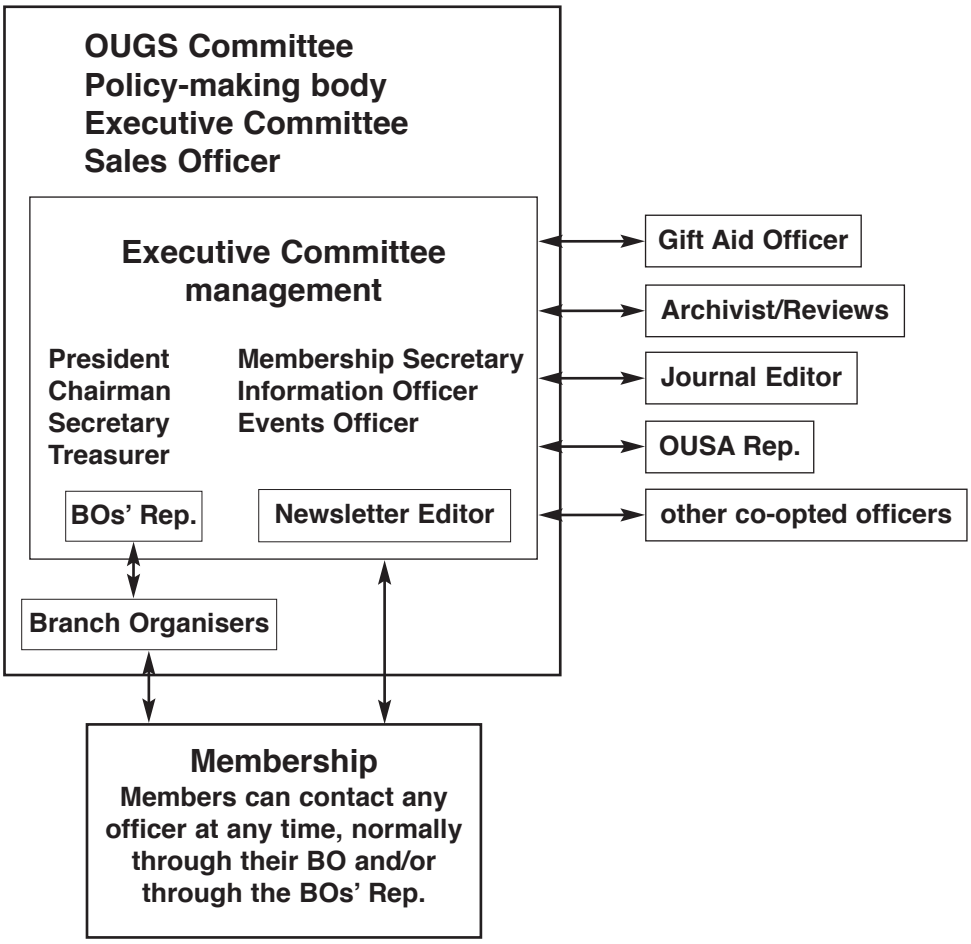

Editorial:

Dear readers,
This issue of the OUGSJ *comprises papers and abstracts for the* OUGS Journal General Issue.

I sincerely apologise to members yet again for a very late issue. These papers for our General Issue were intended for publication at the end of 2013. The General Issue has always included the Geoff Brown Memorial Lecture, delivered at that year's AGM — and was given in 2013 by Dr Ray Burgess of the University of Manchester. The 2013 AGM also included a lecture delivered on the Friday evening at the beginning of the AGM weekend — given by Prof. Tony Grindrod as a new OUGS 'feature', and also intended for publication in the General Issue.

Sadly, however, neither lecturer was able to write up his lecture for publication in the OUGSJ. *We tried hard to achieve this, encouraging the lecturers several times, but in the end it was just not possible for either of them to find the time to complete their papers. After taking advice from the OUGSEC, it was decided to publish their abstracts. Both lectures were most interesting, and should Dr Burgess and Prof. Grindrod be able to write up their lectures for a future issue of the* OUGSJ *we will, of course, publish the papers in full.*

This issue also includes some of the wonderful photographs taken by members and entered into our annual Moyra Eldridge Photographic Competition: Winners and Highly Commended photographs in each of the categories, plus the Popular Vote winner chosen by the AGM delegates attending that year.

Articles in this issue begin with our retiring OUGS President's Field Trip, which in 2013 was led by Dr Nick Rogers to the Isle of Arran. Dr Rogers did his own undergraduate fieldwork there for his final-year project.

Two of our members give us their geological thoughts and interpretations. Chris Popham has thought a lot about the formation of Britain's highest mountain, Ben Nevis. Having 'done Ben Nevis' myself, and collected samples of the rocks Chris describes, I was especially interested in reading his interpretations of the mountain's formation. And Terry Cox gives us his thoughts about the nomenclature of igneous rocks — a seemingly esoteric practice that sometimes involves 'national pride' as well as objective science.

Phillip Clark has written an interesting article on the historical geology of Bromyard in north-east Herefordshire, connecting the elements of a coal merchant, a quarry, a railway, Linton Tile Works and two actresses!

John Downes has written us another of his splendid field studies of Welsh geology, this time on the Tywi Drainage Basin in Carmarthenshire. John describes its ORS, Silurian and Ordovician geology and geomorphology and tells us where to find the best exposures to see it.

For you volcanologists there is a real treat provided by Dr Michael James of the Lancaster Environment Centre, Lancaster University, about imaging techniques used to analyse active volcanic flows. I'd like to say that Dr James's paper is hot off the press (well, in a sense it is), but also thank Mike for his patience in waiting to have his article published and for his help on the image figures.

And last but certainly not least, for you mineralogists we have the conclusion to their papers on zeolites by Oneta Wilson and Alan Dyer, joined for this second part by David Green. I would like to thank them also for their patience in waiting to have the second part of their study published. The photographs of zeolites in this last article are so splendid that I've chosen to feature some of them on this issue's cover.

As always, I wish you happy reading.

— David M. Jones, OUGS Journal Editor

Errata

OUGSJ 34 (1), page 32
To my chagrin, I managed to state an incorrect publisher in my review of Selden, Paul A., and Nudds, John R. 2012 *Evolution of Fossil Ecosystems* (2nd edn): "Manning Publishing" should be "Manson Publishing". The ISBN and other information are correct.

Also, a second error is in the list of Lagerstätten in the antepenultimate paragraph: "[5] The Hertfordshire Nodules (in the middle Silurian rocks of Hertfordshire, England)", should, of course, read as "[5] The Herefordshire Nodules (in the middle Silurian rocks of Herefordshire, England)"

I apologise for these errors. [Ed.]

Earth's Physical Resources at the Open University — Friday at 7.30 p.m.

Prof. Tony Grindrod (Open University)

Editor's note: This was a Friday evening lecture at the opening of the AGM weekend, a new 'feature' in our AGM programme, encouraging members to come for Friday evening as well as for the Saturday AGM.

Abstract only — please see Editorial

The various presentations of The Earth's Physical Resources (Open University) have generated high-quality and innovative texts and course materials widely used by other universities and indiustry. Ian Gass had a passion to make Earth Science relevant to a wide audience and had a knack of inviting just the right external specialists to augment the talented in-house team, which included in the early years Steve Drury, Chris Wilson, John Wright, Geoff Brown and Erc Skipsey. This work culminated in the fine series of books, with Peter Sheldon as editor, for a superb course, which was culled before it had reached maturity.

As the world population increases explosively and our demand for energy rises, we are faced with finding new sources of that energy, while trying to meet targets to limit climate change. It is my contention that the UK and many other countries will not meet the 2020 and 2050 targets and the 'binding' emissions limits will have to be reset.

In this talk we look at the transition from conventional fossil fuels to unconventional sources, and some of the problems for introduction of new technologies. Ultimately we need a 'basket' of all energy types, including fossil fuels and so-called renewables, but this will not come cheaply. Fuel poverty will be a desperate problem needing a desperate solution. The transition to electric cars and trucks has been slow, and the aviation industry has barely started to look at new power plants.

The Geoff Brown Memorial Lecture – Saturday at 5.00 p.m. Hot rocks in cold climates: fossil hydrothermal systems in Antarctica

Dr Ray Burgess (Manchester University)

Abstract only — please see Editorial

Plutonic and subvolcanic igneous rocks are a new and promising source of paleotemperature reconstruction. Hydrothermal systems, which developed around cooling plutons, imprinted the hydrogen isotope signature of the local waters on the hydrothermally altered minerals of the intrusive rocks. By knowing the temperature of water interaction and the age of the intrusion it is possible to reconstruct the surface temperature at which the water was originally formed as precipitation from the atmsophere. As such the fossil hydrothemal system acts as a 'climate station' recording the paleotemperaure at the time of emplacement.

Applying this approach to hydrothermally altered minerals from a series of intrusive rocks emplaced 25–60 million years ago along the coastal areas of the Wilson Terrane, Northern Victoria Land, Antarctica, has provided the first Antarctic terrestrial record of climate variations through the Cenozoic. The Cenozoic land surface temperature data for this remote area located at 73–74ºS latitude is crucial to understand how, when and possibly why, the climate changed in continental Antarctica before and during the greenhouse to icehouse transition at the late Eocene–early Oligocene transition.

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Editor's notes to contributors

Following are guidelines for the submission of articles to the *OUGS Journal*. The principal theme encompassed within these guidelines is 'please keep it simple'. Let your editor do his job and please do not try to simulate, emulate or reproduce the page layout of the *Journal*. I have dedicated page-layout software (QuarkXPress) to do this and any special formatting, special characters and embedded illustrations that you include in a word-processing document can be lost (at best) or seriously confuse and crash (at worst) my iMac or the QuarkXPress software when I import it into the layout.

If your article contains special characters (such as mathematical symbols), please draw these to my attention (I will probably spot them anyway) so that I can import them properly with the glyphs menu in QuarkXPress.

Here are the basic guidelines. I will contact you about any queries that arise when I read your article. I will send you an edited version, showing you any changes that I have made and raising any queries or requesting any missing information.

Guidelines for *OUGS Journal* articles

As *OUGS Journa*l Editor I do not want the publication of your paper to be more work than is necessary for you (or for me!). Your paper need not be more than about 1,500 to 4,000 words in general, but I leave the length up to you to suit the material.

Regarding papers from the presenters of lectures at the OUGS Symposium, all OUGS members are grateful to you for presenting a talk at the OUGS Annual Symposium, and for agreeing to submit a version of your talk for publication in the *Journal*. The purpose of this is to make your information available to OUGS members and others who could not attend the symposium. As OU students and OUGS members we enjoy hearing and learning the information these symposia bring to us.

All that is necessary is the following:

• A Word (or compatible) file of the text: There is no need for you to attempt to format the text in any way using tools in Word or other word-processing software. I will do the page layout format in the *Journal* house style, using dedicated publication-industry-standard page-layout software (QuarkXPress). However, feel free, if you wish, to use **bold** and/or *italics* to indicate headings and subheadings so that I can set these into house style.

I do not require a hard copy, but if you need to point out special characters or attributes in your paper, it may be a good idea to send one with these items marked up or otherwise highlighted. Otherwise I can accept electronic files attached to an e-mail, or files on a CD.

• Each illustration, chart, graph, map or other illustration as a separate digital file in high resolution: 350dpi minimum for colour or half-tone images; 1400dpi for line illustrations. Tables composed in Word or Excel are fine, as they are just text. A rough guide to the number of figures in an article is 10 to 15. Obviously as a symposium presentation speaker you might have shown numerous slides, so please use your best judgement on the number to include with the paper to be published — again usually 10 to 15 is a rough guide. *Please note that figures are normally printed in greyscale in the* OUGS Journal*, except Moyra Eldridge Photographic Competition winners' photographs.*

• Please be sure that we have permission to publish any illustrations that are not yours: Also, please give me the appropriate information to cite in acknowledgement in the figure caption; and please tell me in writing or in an e-mail message that you have obtained the permission necessary for each illustration in your article that is not yours.

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• You can submit the material as attachments to e-mails to me or send it to me on a CD: I am on BT Broadband, so I can receive large files. It is usually best to attach only a few illustration files each to several e-mails. This applies especially to large files of photographs, charts and graphs.

• Where appropriate, cite your sources, or make it clear that a statement is a supposition, or solely your own view or opinion. We use Harvard style citations in the text: (author date, pages), e.g. (Jones 2004, 51–3); and your sources or references should be listed in alphabetical order by author and date at the end of your article. You need to list the author, date of publication (or of access to a web site), full title, periodical volume and number, or place of publication and publisher, and page numbers.

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The Oxford English Dictionary

The Penguin Spelling Dictionary 1990. London: Penguin Books Ltd

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Open Universty Geological Society Presidential Trip to the Isle of Arran (13–18 May 2013), led by Dr Nick Rogers

Chris Arkwright, Tony Loftus, Alan Mack, Nick Rogers and Jane Schollick

Introduction — *Nick Rogers*

Arran is a classic location for training undergraduates in field geology; your President is no exception, having spent at least three weeks here in the early 1970s, studying and mapping the geology and collecting samples for study back in the lab for my final-year project. I eventually published the results from that project on the Creag Dubh sill at the north end of Whiting Bay in the *Geological Magazine* (Rogers and Gibson 1977), my first and only paper on Arran or the Scottish Tertiary Province. So this Presidential trip is something of a trip down memory lane for me as well (Fig. 1).

Arran is often described as Scotland in miniature and that soubriquet can be equally applied to its geology as to its scenery. While the Late Archaean Lewisian and Proterozoic Moinian metamorphic rocks are not represented on the island, rock units from the Neo Proterozoic-Palaeozoic Dalradian, the Lower Palaeozoic Highland border Series, sediments from the Upper Palaeozoic and Mesozoic, and the Tertiary (Palaeogene) igneous activity — not to mention some classical glacial geomorphology — are all represented in a relatively compact area. So in a week a student can be exposed to the various pleasures of igneous, sedimentary and metamorphic geology in a variety of intriguing (and often perplexing) structural settings. Hopefully this set of four day-excursions will offer you some insight into these delights and provide an engaging introduction to the range of geology Scotland has to offer without too much time spent in the bus.

Day 1: Glen Rosa — *Tony Loftus*

The first day involved a walk up the scenic valley of Glen Rosa, a short distance from the hotel in Brodick. We would progress from the Old Red Sandstone (ORS) of Lower Devonian Period, through the Dalradian (Lower Cambrian) and so to the impressive Palaeogene intrusion of the northern granite. The updoming of this intrusion 60Ma and subsequent weathering has exposed the older Dalradian rocks adjacent to the granite. The BGS map (BGS 2007) shows the dip to be subvertical with the younger ORS beds overturned. The walk also examined the geomorphology of the glaciated landscape.

At the first stop, the meandering Glenrosa Water brought back memories of S276, with its point bar deposits and helical water flows. A terminal moraine across the river attested to glacial retreat at the end of the Loch Lomond Readvance; and two river terraces, one about 3m above the other, could be seen (Fig. 2, *overleaf*). Such terraces form as a result of changes in sea level, which in this case was a balance between a local fall in sea level due to isostatic rebound, with the removal of the Loch Lomand ice sheet, and the eustatic rise in sea level as global ice sheets melted. Raised beaches and river terraces are common all over Arran, but correlating terraces and raised beaches seems to be problematic because the latter outnumber the former.

Along the path, deposits of a soft white mineral — baryte — were seen (Fig. 3, *overleaf*). Baryte ($BaSO_4$) was formerly mined in Arran; indeed an adit can be seen high on the hillside opposite the path. It occurs in veins in conglomeratic ORS, having been formed by hydrothermal action, probably in the Carboniferous.

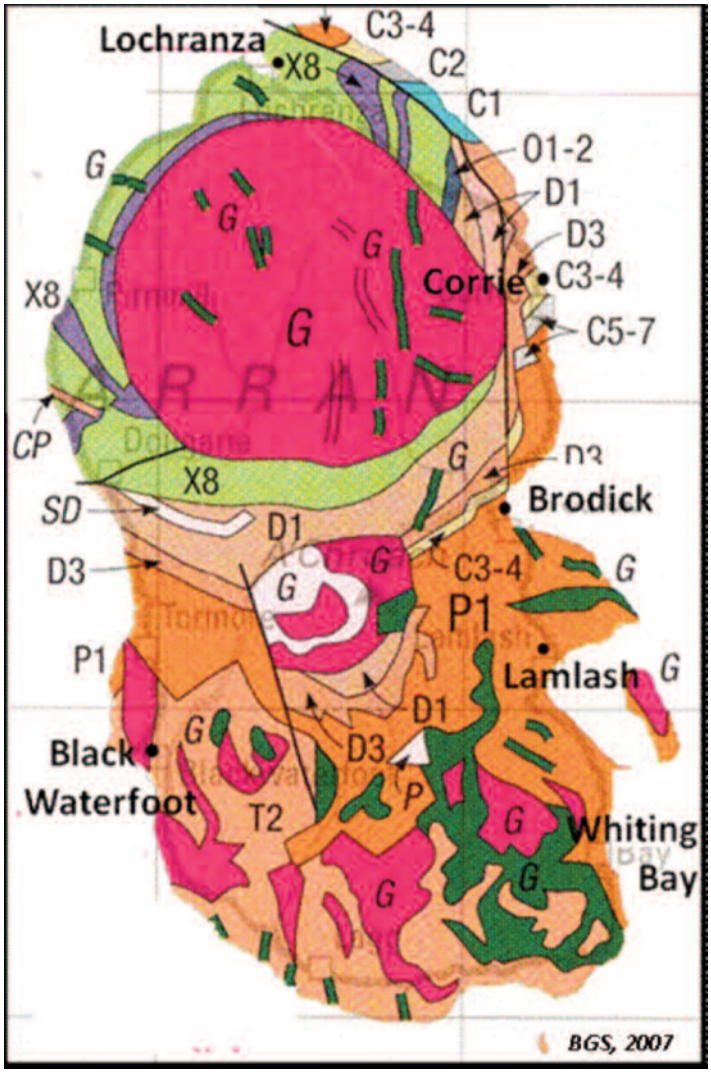

Figure 1 Geological base map.

Key

T2	*Upper Triassic*
P1	*Lower Permian*
C5-7	*Carboniferous Westphalian*
C3-4	*Carboniferous Namurian*
C1-2	*Carboniferous Limestone*
D3	*Upper Devonian ORS*
D1	*Lower Devonian ORS*
O1-2	*Ordiovician*
G	*Palaeogene Intrusions*
CP	*Carboniferous to Permian Intrusions*
SD	*Silurian to Devonian Intrsusions*
X8	*Dalradian Metasediments*

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Figure 2 Glen Rosa, showing terraces formed by sea-level changes (photograph by Tony Loftus).

Farther on, an exposure of ORS near the river was greener in colour than the more usual dark red, a result of contact metamorphism at the time of the granite intrusion, which led to the formation of chlorite from clay minerals. Pale green epidote from hydrothermal action can be seen in joints, but unfortunately were not seen by this group on this cold and wet occasion! The inclement weather also dissuaded us from searching up the hill for the contact between the Dalradian and the ORS. The contact was formerly identified as a fault, but is now considered to be an unconformity.

We next moved on to see Dalradian outcrops — rocks initially formed by turbidity currents in a submarine fan complex during the early Cambrian. Metamorphism and folding of the greywackes and shales under greenschist facies conditions followed in the Grampian Orogeny. The contact with the granite is not exposed here, but was determined to within a couple of metres. Figure 4 shows Dalradian schist close to contact with the granite. At this point the rock was clearly baked by contact metamorphism to form hornfels. The bluish colour is due to the presence of cordierite, although this distinction is too finely divided to be seen with a hand lens. The contact metamorphic aureole is small, as the granite seems to have been cool and partially solid when emplaced.

Climbing up the bank of a small tributary to the Glenrosa Water, and indeed farther up the Glenrosa itself, revealed the granite to be coarse grained. Quartz and two feldspars were evident. The feldspars are identified in the guide as the alkali series end members, but no perthitic texture was evident in the field. As the granite cooled, magma of similar composition filled shrinkage cracks and formed aplite veins of microgranite (Fig. 5, *opposite*).

Figure 3 Baryte in ORS along the path into Glen Rosa (photograph by Tony Loftus).

Figure 4 Cleavage in Precambrian Dalradian schists (photograph by Tony Loftus).

Figure 5 The Northern Granite with an aplite vein (photograph by Tony Loftus).

Figure 6 Dolerite dyke eroded by the stream to form a deep gully (photograph by Stephen Darlington).

To finish the day, a group of us carried on upstream to investigate the course of a dolerite dyke, which has been preferentially eroded by the river to form a deep gash, deep enough to prevent access (Fig. 6)! Its continuation into the ridge some 3km ahead results in the famous Witch's Step.

After lunch we walked back down the glaciated U-shaped valley, relieved to see blue skies appearing at last over the snow-covered tops (Fig. 7).

Figure 7 Glen Rosa, a glacially-eroded, U-shaped valley, with Goat Fell and the Witch's Step on the skyline (photograph by Tony Loftus).

Day 2: Loch Ranza and Catacol — *Jane Schollick*

On a bright, sunny day cooled by a northerly breeze, we set out to explore some of the northern coast of Arran. Stopping briefly at North Glen Sannox, we examined the gritty-textured greenish (chlorite-rich) Dalradian Grits, in which cleavage showed only in the fine-grained layers. They had been subjected to low-grade metamorphism, which affects the clay minerals (e.g. mica) in shale far more than quartz in sandstone. Close examination revealed that cleavage and bedding were aligned, both dipping steeply to the south-east. The graded beds fined upwards from coarse-grained sandstones to fine-grained phyllites, indicating that they were younging upwards — i.e. they were 'the right way up'. These turbidite sediments had been deposited *c.* 600Ma ago in the Neoproterozoic and were later metamorphosed in the Caledonian Orogeny, *c*. 460Ma ago.

A short drive took us to Loch Ranza, an attractive fjord-like inlet on the north coast. As we walked along the eastern side of Loch Ranza past Newton Point (Fig. 8: locations 1 to 4), we examined the dip and appearance of the Dalradian schists. At location 1 (Fig. 9), the folded, fine-grained, shiny grey schists dipped at *c.* 45º to the *north*, with bedding and cleavage aligned. At locations 2 and 3, the schists dipped at similar angles to the *south-east*, bedding and cleavage still aligned (Fig. 10). The change in direction of dip indicated that the axis of a synform must lie between locations 1 and 2. It was not possible to determine which way the beds were younging, but this was determined later near Catacol.

Looking ahead towards location 4, we noticed beds of reddish-pink sandstone, inclined at an angle of *c.* 20º to the north. Looking back, the folded grey Dalradian schists were still dipping steeply (45º) to the south-east, so we searched for the contact between these very different strata. As the tide was low, it was easy to see the irregular erosional contact between the grey Dalradian schists dipping steeply to the south-east underneath the

Figure 8 Geological sketch map of Loch Ranza and Catacol areas (MacDonald & Herriot 1983).

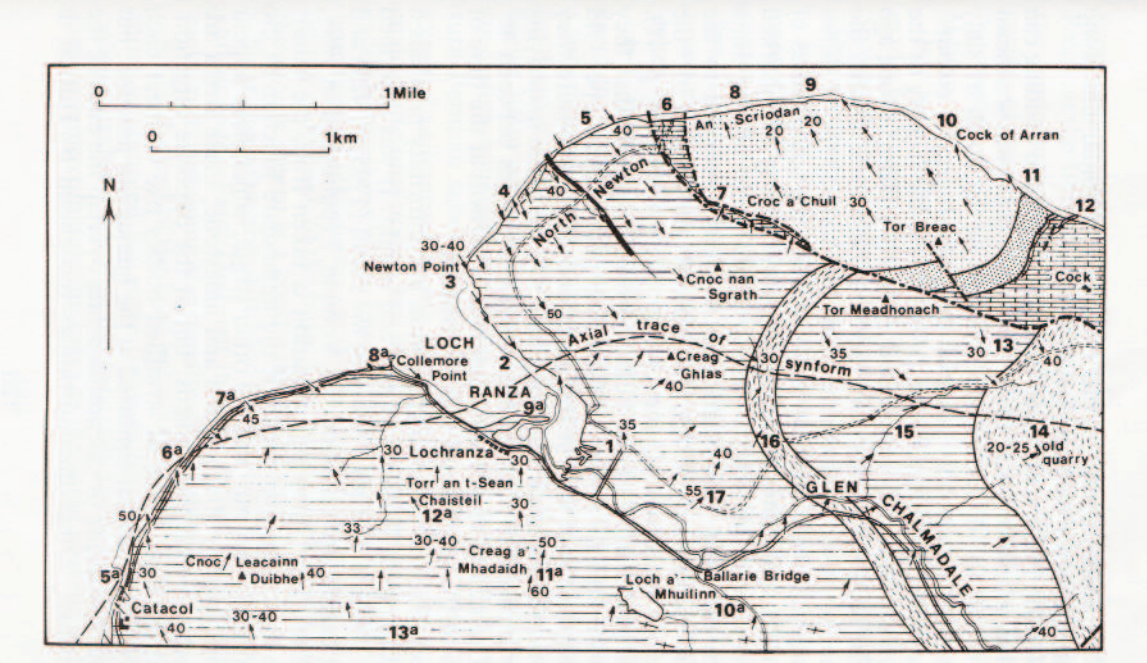

Figure 9 Loch Ranza shoreline schists near location 1 (photograph by Maggie Deytrikh).

Figure 10 Loch Ranza Dalradian schists at location 2 (photograph by Maggie Deytrikh).

Figure 11 Hutton's Unconformity (photograph by Maggie Deytrikh).

reddish sandstone dipping gently to the north (Fig. 11). This contact is known as 'Hutton's Unconformity', as James Hutton was the first person to recognise the significance of this discordant junction, in the late 18th century. He realised that there must be an enormous time-gap (actually *c*. 160Ma) between these two strata, and he said that it was evidence of a 'succession of worlds following one another throughout geological time'. The reddish sandstone, known as the Carboniferous Kinneswood Formation (the earliest Carboniferous formation), had been laid down in an arid environment, as indicated by its red colour (oxidised iron). It is a calcrete (or 'cornstone') because it contains calcium carbonate, as indicated by a positive acid test.

Figure 12 Baked sandstone next to dyke (photograph by Maggie Deytrikh).

After 'gazing into the abyss of time' (said by James Hutton's friend James Playfair on first seeing this unconformity), we walked farther north-east along the coast to discover an eroded north-west trending basaltic dyke cross-cutting both the reddish sandstone and the schists. This Tertiary dyke had chilled margins and had baked the sandstone it intruded (Fig. 12). We noted that basalt is more easily eroded by sea water than either sandstone or schist.

Next we were taken to the modern Arran Whisky Distillery for a tour and lunch. On the tour we were taught how to enjoy malt whisky with 'just a teaspoonful of water' and all the intricacies of the manufacturing processes required to produce different varieties of single malt whisky (Fig. 13, *overleaf*).

After lunch we examined the Dalradian schists west of Catacol, to the south-east of Loch Ranza. Here the schists had experienced several phases of deformation, as they clearly showed multiple folding. The beds were dipping at *c*. 40º to the north-west and could be distinguished by their different shades of grey. On close

examination, several examples of beds with grit at the top, fining downwards, were found. This indicates that the beds were younging downwards, so were inverted. We deduced that the beds on the other side of Loch Ranza must also be inverted, as they are all part of the same synform.

One explanation is that this synform is part of an eroded nappe, part of the Iltay (or Tay) Nappe, as suggested by Robert Shackleton.

Day 3: Blackwaterfoot, Kildonan and Whiting Bay – igneous intrusions — *Chris Arkwright*

It was another bright, sunny day when we travelled across to the west coast of Arran to look at Tertiary sills and dykes, which had been intruded into the red marls and siltstones of the Triassic Auchenhow Beds during rifting as the Atlantic Ocean started to open.

Moving westward along the shore from Blackwaterfoot, the first intrusion encountered is a pale-coloured, medium-grained felsite consisting mainly of quartz and feldspar (Fig. 14). This intrusion, which stretches for many metres along the shore, is part of the extensive Blackwaterfoot-Torr Righ Mor felsite body. Curious ripple-like structures seen within the felsite caused some discussion (Fig. 15, *opposite*. It is perhaps the start of columnar jointing along a cooling front and, although the expected polygons are not evident here in cross-section, they are seen in other parts of this felsite (MacDonald and Harriot 1983). At the north-west margin of the intrusion, the finer-grained felsite is evidence of cooling against the country rock, while the red and white stripes in the adjacent marls indicate alteration by hot fluids from the felsite by metasomatism (Fig. 16, *opposite*).

Figure 13 Arran Whisky Distillery (photograph by Maggie Deytrikh).

Farther along the beach we encountered a darker-coloured dyke, *c*. 2m wide, dipping steeply to the south and cutting across the westerly-dipping Triassic beds. This basic dyke has

Figure 14 South-east margin of the Blackwaterfoot — felsite (photograph by David Arkwright).

Figure 15 Mysterious column-like structures in felsite (photograph by David Arkwright).

a medium-grained background containing phenocrysts of green olivine and black clynopyroxene, with white felspathic analcime, after nepheline (Fig. 17). This rock type, commonly found on Arran and elsewhere in Scotland, is called a crinanite on older maps and guides. Nick warned us that many rock types had been given local names after the places where they were first mapped, but it is better scientific practice to use the correct petrological classification — in this case, alkaline olivine dolerite.

Figure 16 Felsite-marl metasomatised margin (photograph by David Arkwright).

Figure 17 Porphyritic crinanite (photograph by Maggie Deytrikh).

Next we examined a composite dyke, where basic tholiitic magma had been intruded by a more felsic magma, with clear bounderies preserved (Fig. 18). This dyke is also off-set and cross-cut by faults and other minor dykes, and we spent a few minutes trying to make sense of what came first. But then agreed that perhaps this exercise would be easier using Google Earth!

The intrusion around the shore of Drumadoon Point is a feldspar-quartz porphyry with dolerite along side. On closer examination, we found rounded dolerite xenoliths in the felsic porphyry and resorbed feldspar and quartz zenocrysts in the dolerite. Although we did not examine the high cliffs near by, the main Drumadoon Sill (Fig. 19, *overleaf*) is similarly described in the literature, i.e. a thick felsic columnar-jointed centre containing dolerite xenocrysts with inclusions of felsic xenocrysts in the dolerite above and below the columns.

The following model for emplacement is like a game of geotag (McKerrow and Atkins 1985; Kanaqris-Sotiriou and Gibb 1985):

a. granitic magma crystallised slowly at depth forming quartz and feldspar phenocrysts;
b. basic magma intercepted the granitic magma, incorporating phenocrysts, but without magma mixing;

Figure 18 Composite dyke (photograph by David Arkwright).

c. the basic magma continued rising higher in the crust, intruding Triassic sediments and forming a thin sill;
d. granitic magma is then forced along weak centre of the thin dolerite sill, incorporating ripped off dolerite xenoliths. Figure 20 shows a collection of beach rocks representing the sill, the Triassic country rock and Dalradian scist from farther up the coast.

The plan had been to continue around the southern coast to Kildonan, but a road closure just south of Blackwaterfoot (to repair extensive winter damage) meant instead a return trip across the central Sting Road, through Brodick, Lamlash and Whiting Bay to reach the south coast near Kildonan.

Continuing the day's theme of igneous intrusions, we walked along the beach to examine the numerous dykes, trending south-south-east, intruding the Triassic red siltstones. The views were spectacular. The off-shore Pladda Island (a quartz-dolerite sill) and the distant Ailsa Craig (microgranite containing the blue riebeckite amphibole) were very clearly seen — a photographic opportunity not to be missed (Fig. 21)! The dykes, of varying mafic composition, range from a few tens of millimetres to many metres wide, some being composite and many cross-cut by other dykes or bifurcated.

Returning to Whiting Bay, the last stop at Creag Dubh (Black Rock) was a nostalgic moment for Nick. This composite sill was the subject of his first published paper (Rogers and Gibson 1977), where he spent many happy field days recording and sampling the intrusion, with subsequent analysis in the lab. The sill is *c*. 8m thick, dipping with the Permian sandstones at about 20º south-south-east. The tide was too high to access the base of the sill, but the central and upper parts were easily seen. After examining fresh samples from different levels it was evident that the thick central part of the sill is quartz-dolerite, and the thin top layer felsite. Nick confirmed that the base of the sill has a similar thin layer of felsite. The finer-grained dolerite adjacent to the felsite suggests that the mafic magma had been chilled when intruding the existing felsite sill, thus the opposite model to the emplacement of the Drumadoon Sill where felsite had invaded a thin dolerite sill.

Figure 19 Drumadoon Sill (photograph by David Arkwright).

Figure 20 Rocks on the beach from Drumaddon sill, Triassic country rock (sandstone) and Dalradian Schist (photograph by David Arkwright).

Figure 21 Dolerite dyke, Ailsa Craig and Pladda Island (photograph by Tony Loftus).

Figure 22 Douglas Hotel, Brodick. (photograph by Alan Mack).

A very interesting day and Nick's clear explanations and mineral identification had helped us make some sense of this complicated suite of Tertiary intrusions.

Day 4: Corrie shore and Goat Fell — *Alan Mack*

Another beautifully sunny and cloudless morning. We had spent a week in the luxury of the Douglas Hotel (Fig. 22), quite a contrast to the more basic accommodation experienced on other trips.

Today our objective was to examine the stratigraphy and sedimentology of the Devonian, Carboniferous and Permian outcrops along the shore at Corrie (Fig. 23).

STRATIGRAPHY		
PERMIAN	Corrie Sandstone	~280 Ma
	Upper Limestone Group	~300 Ma
	Limestone Coal Group	
CARBONIFEROUS	Lower Limestone Group (Corrie Limestone)	
	Strathclyde Group (incl. lavas and agglomerate)	
	Inverclyde Group (Kinnesswood Formation)	
DEVONIAN	Stratheden Group	~400 Ma

Figure 23 Stratigraphy of rocks found along Corrie shore (data from McKerrow and Atkins 1985).

Locality 1 [NS 023 442]

Walking south from this point towards Corrie village.

Observations

Bed A (Fig. 24): Red, mainly fine-grained, cross-bedded sandstone, dipping gently to the south-east — honeycomb weathering evident; acid test positive, indicating the presence of calcite. This is the Upper Old Red Sandstone (Devonian) of the Stratheden Group.

Bed B (Fig. 25): Red siltstone with some pale green spots. The red sandstone gets its colour from the more oxidised form of iron oxide (Fe_2O_3) and the green spots are from the reduced form (FeO); reduction may have been due to decomposition of organic material.

Bed C: Red, cross-bedded sandstone of variable fine- to coarse-grained. Where coarse-grained sediments overlie finer-grained beds there are clasts of the finer material within the coarser beds.

Bed D: Fine-grained siltstone with cornstones (calcareous nodules).

Bed E: Conglomerate with both angular and rounded clasts of schist, quartz and sandstone contained in a matrix of fine to coarse sandstone; some slumping and loading structures evident. This conglomerate is the base of the Carboniferous Inverclyde Group Kinnesswood Formation.

Process

Fluvial deposition of locally derived and more distant material, at low energy. There were also some episodes of high-energy flow, when finer-grained deposits were ripped up by strong currents and deposited in calmer condition, these rip-up clasts then being incorporated in the coarser sediments.

Environment

Arran was at equatorial latitudes, drifting northward. Deposition was in a hot, fluvial, low-energy environment with occasional flash flooding. Sediments from periods of flooding that were stranded above normal water level evaporated in the equatorial heat to give rise to calcrete and calcareous nodules. Later flash flooding deposited larger clasts, some angular and some more rounded, the more angular rocks either being more resistant to erosion, or travelling less far.

Walking south to Locality 2 we passed large boulders from the Northern Granite left behind as the glaciers retreated *c*. 11,000 years ago (Fig. 26, *overleaf*).

Figure 24 Bed A: red sandstone with honeycomb weathering (photograph by Alan Mack).

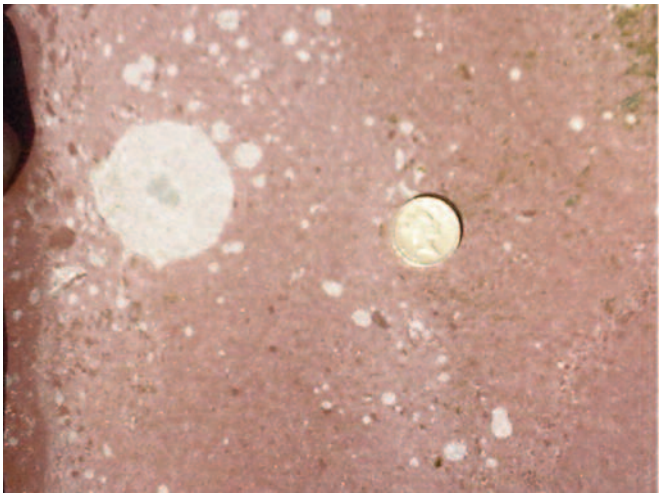

Figure 25 Bed B: red sandstone with greenish reduction spots (photograph by Alan Mack).

Figure 26 Large erratics of the Northern Granite (photograph by Alan Mack).

Locality 3

An outcrop, south of the school, of a fine-grained, crystalline, deep red/purple rock forming a ridge down to the sea; acid test positive — odd for an igneous rock to have a major calcite content? Later, Zoë Gardiner showed a sample of this rock to John Mendum, who thought it had a definite igneous texture rather than sedimentary. He suggested that the fizzing could have been due to calcite in the fine veins and fractures that had penetrated the rock. But the rock seemed to fizz everywhere and the veins were not wide. Chris Arkwright suggested it might be a carbonatite (an igneous rock composed mainly of carbonate minerals).

We had lunch at Corrie Harbour, above which there is a limestone quarry where we observed five or six sequences of deltaic sediments of sand, silt and mud with marine advances marked by limestone beds.

Just south of the harbour is a strikingly pure white sandstone (named Ferry Rock) and a little farther south is the sandstone bed that marks the top of the Carboniferous. There were highly contorted folds in this rock, suggestive of slumping, perhaps due to seismic events (Fig. 28).

Locality 2

Observation

A matrix-supported rock with clasts of basalt and some country rock (sandstone). The matrix gave a positive acid test, indicating the presence of calcite. This rock is an agglomerate and forms the base of the Carboniferous Strathclyde Group (Fig. 27). Close by is a dark green crystalline rock with red patches and crystals of black pyroxene, yellow pyrites and red haematite. Some polygonal jointing was noticed. This is an olivine basalt.

Process

These are rocks formed from volcanic activity, the agglomerate is typically formed from volcanic mudflows of pyroclastic material close to vents; the olivine basalt from lava flows erupted from vents.

Environment

Volcanoes erupting low-silica, basaltic lavas rich in olivine and pyroxene, with related mudflows of pyroclastic material.

Figure 27 Agglomerate at Locality 2 (photograph by Alan Mack).

Figure 28 Contorted folding in Carboniferous sandstone (photograph by Alan Mack).

The outcrops farther south took us into the Permian Corrie Sandstone — wind-blown desert sandstones. These fine-grained sandstones make excellent building stone and were quarried until 1928. Many fine buildings in Glasgow were built from this stone. An interesting non-geological feature here was a bathing pool cut into the rock. It was low tide, so we didn't have the opportunity to plunge into it (Fig. 29, *opposite*).

At this point the bus arrived to take us back to Brodick, but some of us decided to finish the day by climbing the highest peak on the island — Goat Fell (874m).

Goat Fell and the adjacent peaks were formed by erosion of the Northern Granite pluton (Fig. 30, *opposite*). Glaciations in the Late Pleistocene and later (the last ice sheet retreated only 11,000 years ago) have sculpted glaciated valleys (Glen Rosa

Figure 29 Bathing pool cut into Permian sandstones (photograph by Heather Rogers).

and Glen Sannox, Fig. 31), corries (The Devil's Punchbowl), arêtes (the ridge that includes the Witch's Step, Fig. 32) and nunataks (Goat Fell and surrounding peaks and pinnacles that poked above the icesheet). The clear sunny weather made for fantastic views on the ascent and from the top we had vistas on all compass points, notably Jura to the north and Ireland to the south-west (Fig. 33).

Figure 30 Goatfell from Brodick harbour on the final morning (photograph by Alan Mack).

Figure 31 Glen Sannox (photograph by Alan Mack).

Figure 32 Ridge of North Goat Fell (right) and the Witch's Step (left) in the distance (photograph by Alan Mack).

Epilogue

The weather had been kind for most of the week and it was sunny and warm for the last day of the OUGS Presidential Trip to the Isle of Arran. As we made our way down from Goat Fell in the gloaming, descending the length of Glen Rosa back to Brodick, I thought of the events of our trip. In the four days on Arran we had seen a showcase of geology: sedimentary rocks representing most systems from the Cambrian to the Pleistocene; igneous rocks represented by pillow basalts, sills, dykes, quartz-feldspar-porphyry, pitchstone and the great Northern Granite pluton; metamorphic rocks represented by Dalradian schists and by thermal aureoles of the larger intrusions. As in all good field trips there were things we had to leave for a future visit, among these the collapsed caldera of the Central Ring Complex and examples of 'fossilised lightning bolts' (fulgurites).

Special thanks to Nick Rogers (leader) and to Chris Arkwright (organiser) and all the OUGS members from far and wide for a week I shall never forget!

Figure 33 On the summit of Goat Fell, looking north (photograph by Alan Mack).

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Ben Nevis: an appreciation of the geology from the 'Tourist' footpath[1]

Chris Popham[2]

Introduction

About 500 million years ago (Ma) in a geological period known as the Ordovician, the part of the surface of the earth that was to become Scotland was forming in the depths of the Iapetus Ocean.

Gradually, as the result of tectonic movements during the late Ordovician 450Ma, the ocean basin began to close as ocean floor subducted under a neighbouring plate, resulting in the formation of an island arc of volcanoes close to the subduction zone. Massive quantities of ash and lava were ejected, forming these islands and new sediments on the ocean floor. Eventually, 400Ma at the close of the Silurian period, the subduction process brought the landmasses together during a phase known as the Caledonian Orogeny, which raised a mountain range over most of what is now Scotland. There then followed a long period of erosion and submergence before once again a continental collision during the late Carboniferous Period, 280Ma, caused another mountain building event, the Variscan Orogeny, which significantly elevated England and Wales but left Scotland largely unaffected.

The evolution of Glen Nevis

Over the last 1.4 million years glacial events have exposed much of the underlying geology as well as shaping Ben Nevis, which, with an elevation of 1,344m is the highest mountain in the UK, as well as creating the distinctive scenery of Scotland.

Ben Nevis initially began to develop when a pluton of granitic magma formed beneath the basement schist rocks, which were a that time already about 500 million years of age. A block of the basement schists then foundered into the magma, which pushed up over the block forming a ring dyke now termed the 'outer granite' (the British Geological Society puts the age of this granite at 416–444Ma). A phase of volcanic activity followed during which a series of linear dykes were intruded, cutting through both outer granite and surrounding rocks. The schist block then broke away from the outer granite, settling farther into the magma and another ring dyke formed, called the 'inner granite' (BGS age 416–444Ma). In all about 600m thickness of granite came to overlie the foundered schist block. The linear dykes are the key to interpreting this series of events, as they cut through the basement rocks and outer granite, which must therefore have been in place and solid, but are absent from the inner granite, which must therefore have been intruded afterwards.

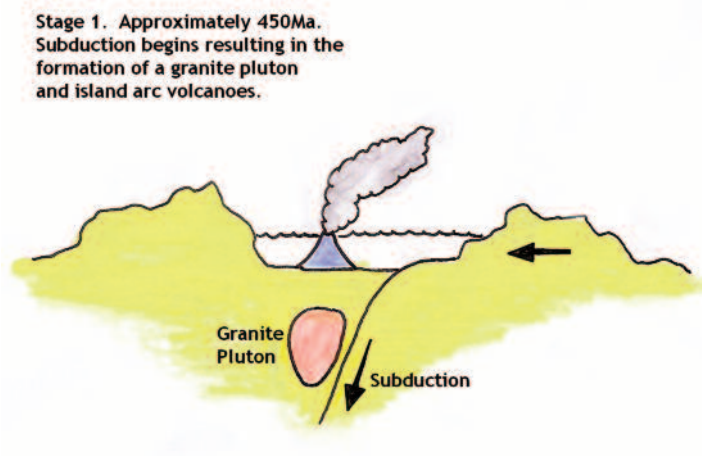
At this stage the mountain was considerably higher than at present, but, in the final stage of its evolution, the cone collapsed, creating substantial eruptions of lava and tephra (BGS age 398–419Ma), which are now presented as the top 500m or so of the mountain. One of the clearest descriptions of the events is given in the on-line document http://www.snh.org.uk/pdfs/publications/geology/bennevisandglencoe.pdf by Scottish Natural Heritage and the BGS, entitled 'Ben Nevis and Glencoe'. However, that interpretation and most nearly all other diagrammatic interpretations (especially those on-line) are seemingly copies of a dated and, I would argue, inaccurate interpretation showing just four stages in the evolution of the mountain. Nearly all (including the Scottish Natural Heritage interpretation) show the andesites that form the top of the mountain being present when the inner and outer granites were being intruded, despite the fact that dating shows the andesites to have an age younger than the granites, while simultaneously and confusingly most descriptions that accompany the four-stage diagram describe the andesites as resulting from eruptions during the final stage of volcanic activity. Most of the diagrammatic interpretations also show a level land surface, even though (as has already been discussed) the setting was apparently that of an island arc and later a continental suture.

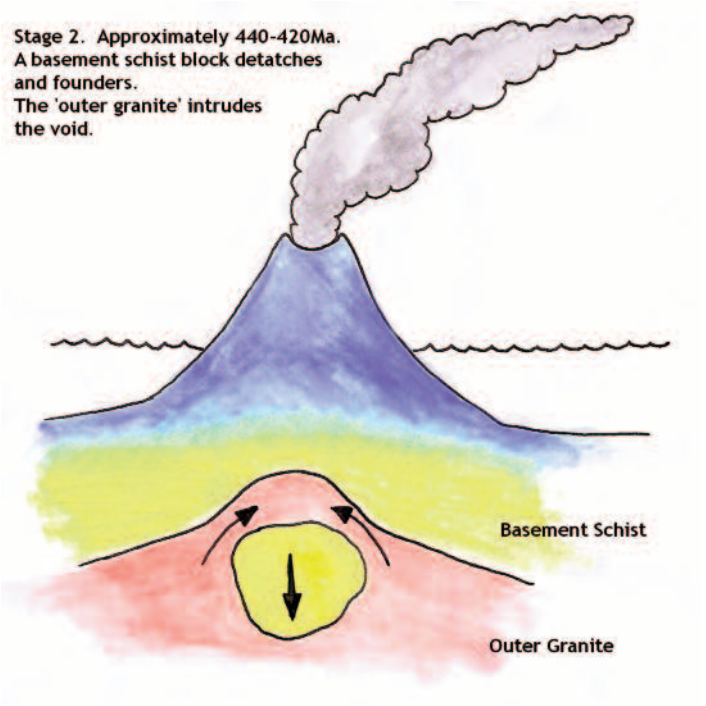
A new proposal

The following is proposed as an alternative diagrammatic series depicting the evolution of the mountain (Fig. 1 — six stages).

In general, the geology of the mountain is best appreciated during a descent from the summit. The mountain has experienced

Figure 1 Diagram of proposed alternative evolution of Ben Nevis, as six stages — Stages 1 & 2 (© Chris Popham). [see also next two pages]


Stage 1. Approximately 450Ma.
Subduction begins resulting in the formation of a granite pluton and island arc volcanoes.
Granite Pluton
Subduction


Stage 2. Approximately 440-420Ma.
A basement schist block detatches and founders.
The 'outer granite' intrudes the void.
Basement Schist
Outer Granite

© OUGS ISSN 0143-9472

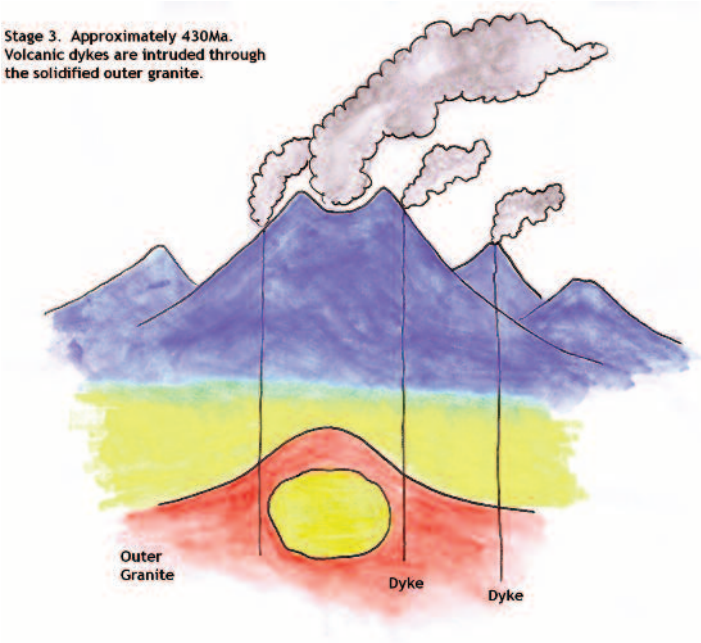


Figure 1 Stages 3 & 4 (© Chris Popham).

significant natural erosion due to glacial processes over the past 1.4 million years, but there has also been a significant human intervention over the past 100 years as the popularity of the mountain with walkers has increased and the footpath network has been developed. In general, these forces have resulted in both a down-slope movement of Ben Nevis' native material and a build-up of materials brought in from elsewhere. To either side of the path the rocks are mostly covered by lichens, grass or periglacial head deposits and the underlying rock cannot be appreciated. In general, however, native rock has not moved up the slope so working down from the summit it is generally the case that the first exposure of a rock type in the footpath represents its natural limit of occurrence.

The mountain summit is a small plateau that was home to a weather observatory for many years, from which several ruins remain. One building stands on top a large cairn of stones and there is also the cairn for the Ordnance Survey trig point. These factors, along with the changes brought about by the footfall of 150,000 visitors a year, mean that the plateau is not the best place to appreciate the summit geology. Also, unless you are fortunate enough to pick one of the 10 days a year when the mountaintop is clear of cloud, you will not be able to appreciate that to the north-east the mountain falls virtually sheer at the inner caldera wall, while to the south and west the slope profile is that of a shallow dome.

Descending from the summit the rock is a mix of hornblende andesite interbedded with lavas from the final eruption stage. Differentiating these units is not easy, as they both appear as uniform mid-grey-coloured rock, silica poor, with white feldspar phenocrysts.

Nevertheless, while the hornblende andesite accounts for the majority of the structure of the summit down to the 850m contour, it is by no means uniform. At around the 1,150m contour (a little above the permanent snow line) there is an outcrop of fragmented pyroclastic agglomerate, which is readily distinguished because weathering has given the surface of the rocks a

Figure 1 Stages 5 & 6 (© Chris Popham).

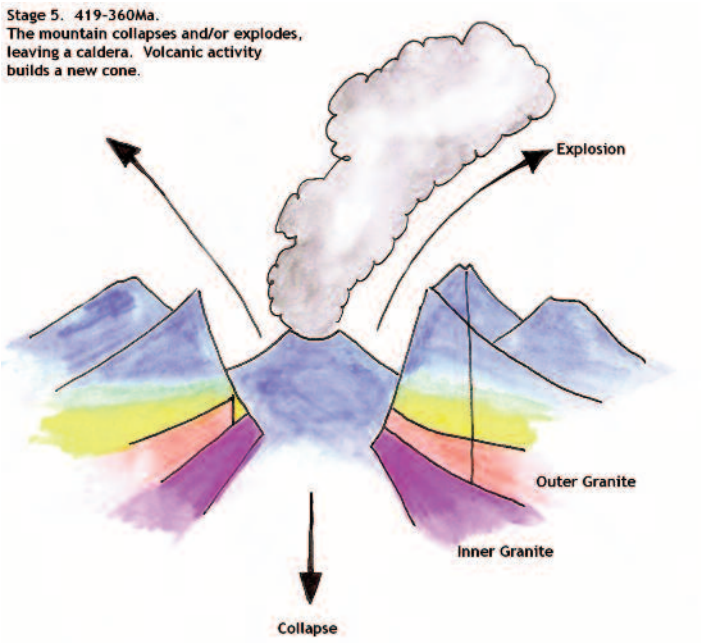


Figure 2 Hornblende andesite (photograph by Chris Popham).

Figure 3 Agglomerate (photograph by Chris Popham).

pronounced yellow hue (Figs 2 and 3). This agglomerate has a highly varied structure and in some places the structure is clast supported, whereas other pieces break open to reveal a uniformly fine-grained structure with a distinct green hue. While erosion may not have moved rocks uphill, the final collapse of the caldera caused the ejection of substantial amounts of already solidified granite, of which many pieces can be seen on the upper slopes. But, as the 850m contour is approached, clearly what are granite intrusions rather than fallen rubble become noticeable.

Below the 850m contour the inner granite is exposed and this coincides with the first significant growth of grass (for 150m above this the grasses become increasingly stunted and coarse and above that it is just lichen, moss and bare rock). This granite is silica rich and was formed *c*. 430Ma, and is described by the term Leucomicrogranodiorite by the British Geological Survey. It is predominantly pale in colour, either white or pink with a fine-to-medium crystalline structure.

Again the mountain's structure is not uniform and at about the 680m contour the path crosses over the Red Burn, where it is worth looking out for substantial blocks of agglomerate that have been used in the construction of the path. Some of the blocks are of a significant size, which would preclude them having been brought in to make up the path. It is therefore not unreasonable to assume that there is either a bed of agglomerate at this contour level or that the blocks have run down the mountain side in a fall, as their distribution is restricted to about a 150m linear run of the path, which here traverses the mountain side at a shallow angle (Figs 4 and 5).

Where the path crosses the Red Burn it makes a long northward traverse of the mountainside, heading down to a saddle between the mountain and the raised ground of Meall an t-Suidhe. The saddle is almost entirely occupied by Lochan Meall an t-Suidhe, a shallow lake that sits just below the outer-inner granite contact. This lake appears not to be the result of direct glacial action, but rather has been trapped by glacial moraines and solifluction

Figure 4 The dome shape of the mountain above Lochan Meall an t-Suidhe (photograph by Chris Popham).

Figure 5 Inner granite (photograph by Chris Popham).

Figure 6 Outer granite (photograph by Chris Popham)

Figure 7 Schist from the river gravel (photograph by Chris Popham).

deposits at both the north and south ends of the saddle. The flow of water is predominantly off Meall an t-Suidhe, where the western lakeside is a delta of tiny streams down among the grass. The flow out of the lake is then northward. The soil at the southern end of the lochan supports thick grass cover, bog cotton, a few low bilberry plants and also pink and white orchids.

The inner and outer granites are exposed alternately from just below the lochan as the path apparently zig-zags across the contact. Just below the lochan (NN142719) the path follows a zone of nearly white, fine-grained granite, which has the appearance of a dyke, possibly of inner granite, intruded into the older outer granite. Just below this feature there is a distinct zone where coarse, decidedly red granite is cut by many red veins of microscopically crystalline material, which may be rapidly cooled rhyolite (as described by the BGS) intruding the outer granite, although in that case the strong colouration is anomalous. While it would be a gross oversimplification, it is somewhat true to say that the inner granite is paler and more finely crystalline than the outer granite (Figs 6 and 7).

Many dykes of various compositions cut the outer granite. Where the path makes a turn (approx. NN140717), the BGS map indicates that it follows a dyke of microgabbro, an intrusion dated to just 24–65Ma.[3] Although the microgabbro is not immediately obvious by colouration or structure, at NN139717 there is apparently a very pronounced pahoehoe lava flow in the bank of the path a short distance above the first (on the descent) footbridge (Fig. 8). This is dark material, weathering to brown iron oxides with a distinct onion-skin-like structure (Fig. 9). The rock also appears to have a high specific gravity and under the ordinary light microscope there appear to be small phenocrysts of biotite in it. These characteristics would seem to indicate that this has a mafic composition and may be associated with either the microgabbro or the lamprophyre dyke (*c.* 400 million years old), which the BGS map indicates is above the path at this point.

However, the BGS indicates that both the microgabbro and lamprophyre were intruded at depth, which is not consistent with the apparently pahoehoe appearance, and which suggests that the lava is not associated with either intrusion.

Below this point the granite becomes increasingly porphyritic, with large red feldspar phenocrysts, but again at a zig-zag in the path (NN133720) there is a pronounced intrusion of fine-grained

Figure 8 Pahoehoe lava flow? (photograph by Chris Popham).

Figure 9 Onion-skin weathering (photograph by Chris Popham).

black rock. This may be basaltic and this outcrop would seem to coincide with a lamprophyre dyke marked by the BGS. Unfortunately, no loose samples were available for later microscopic examination.

A little below the dark intrusion the path forks left and descends steeply to the youth hostel. Here the path crosses a zone of quartz diorite and then a zone of limestone down to the footbridge over the river, although neither zone is immediately apparent because the path has been fully made up with laid stones and the slopes are heavily vegetated. Nevertheless, a short foray onto the river gravels will yield samples of the aforementioned rock types, as well as of the basement Leven Schist into which the mountain was intruded.

Endnotes

1 The Tourist Path, as it was called, is the most used and gentlest route up the mountain. Latterly the path has been designated the 'Mountain Track' to deliver a message to walkers that proper preparation is essential. The path begins at the Ben Nevis Visitor Centre (BNG NN122730) in Glen Nevis where there is a large car park. Alternatively, if you are staying in the Glen Nevis campsite, as we did — and it is a pleasant site — there is a footbridge over the river near the youth hostel and a zig-zag 'shortcut' to join the principal path.

I would not regard any part of the path as particularly challenging, as it is for the most part well surfaced, although there are a few little clambers over large rocks, particularly in the section just below the saddle that contains the Lochan Meall an t-Suidhe. The section from the lochan to the Red Burn is almost continually surfaced in gravel, but becomes rougher from there to the next turn. Beyond that, the slope of the path sharpens and the surface is more uneven or made up of larger loose stones. It was at about this elevation (800m) that we entered the cloud cover.

Towards the summit the path again starts to traverse the mountainside at a shallow angle and crosses a field of permanent snow. The mountaintop has several snow fields and is shallow to the summit, but be very cautious as the path in places is just a few metres away from a long vertical drop, and it was my impression that the cloud cover was coming up the wall, making the edge impossible to see. Where it could be seen it was evident that the snow had formed overhanging cornices.

We walked the path on July 3rd and while the weather conditions at the foot of the mountain were good visibility, slight breeze and temperature *c*. 17–18°C, at the top of the mountain visibility was almost zero at times and 20m at best, there was a stern wind and the temperature was just 5–6°C, not allowing for the wind chill, which probably took it down to 1–2°C. While we were all experienced mountain walkers and had coats, hats, gloves and other essential gear, there were people in T-shirts and thin trousers who were not enjoying the experience or turned back before the top.

In all it took us about three hours up and two hours back down, and we ended our day with a very pleasant supper at the (somewhat predictably named) Ben Nevis Inn just across the footbridge from the visitor centre. In the late afternoon the cloud cleared from the mountaintop for an hour or so, giving us a clear view of the north face from the Fort William to Spean Bridge road. The cloud then returned bringing lightning and, we were told, a significant fall of snow at the summit.

Similarly, the day before we had climbed Scafell Pike at only 980m and several hundred miles farther south, and very similar conditions prevailed: mild in the valley, but well below freezing in the wind at the summit.

All walkers are advised to leave details of their group, planned route, proposed return time and contact numbers at the shop / reception of the Glen Nevis Camp Site, or for Scafell Pike at the Wasdale Head Inn or other suitable establishment if climbing Scafell Pike from another one of its several route approaches. Both places are very willing to take your details, but you must also then let them know once you are off the mountains.

2 Chris Popham has also written accounts of the geology of Scafell Pike and of Snowdon. See 'Mount Snowdon and Scafell Pike: a comparison of the geology and present-day surface features' (*OUGSJ* **30** (1) 2009, 47–53.

3 Personal communication — I consulted Martin Gillespie of the BGS, who tells me, "The Ben Nevis intrusions have not been dated directly by radiometric means, and the BGS Geology Viewer assigns all of the intrusions to the same chronostratigraphical unit — the Silurian System; hence, the same relatively broad age-range is quoted for the different intrusions. However, field evidence indicates that the 'Inner Granite' is younger than the 'Outer Granite', and it is likely they were in fact separated by no more than a few million years."

Book review

Ross, Aandrew, and Sheridan, Alison 2013 *Amazing Amber.* Edinburgh: National Museum of Scotland (ISBN 978-1-90526-779–8; paperback, 63pp; £6.99)

Amazing Amber is a short book published to coincide with an exhibition at the National Museums Scotland, running from 10th May to 8th September 2013. It is intended as a companion book to the collection. It is intended to be read while browsing the exhibits, but is an interesting read in its own right.

The book is divided into several chapters that explain what amber is and where it comes from, how it has been used in arts and crafts, how amber can be 'faked' and, of course, insects that can be found embedded within it. There is brief explanatory text to give each piece context, but most of the book consists of excellent images of some of the exhibits.

Some of the pieces are extraordinary. In one inclusion, a flying ant has been caught in the act of carrying a scale insect away. Some include long-extinct species, others represent new discoveries, seen by human eyes for the first time. Even spider webs have been preserved in some pieces. There are examples of amber jewellery and charms, of artwork, of aristocratic accessories and of grave goods. My favourite is a fungus, literally caught in the act of releasing its spores.

Perhaps the only disappointment is that the text isn't quite detailed enough for the interested amateur, though of course the book is aimed at a lay audience. A comprehensive bibliography is provided for anyone wishing to study further. All in all, Amazing Amber is a fascinating introduction to this amazing fossil, and even if you can't get to the exhibition the book alone is still fascinating.

— Richard Blagden Dip HE (Open)

Book review

Lunine, Jonathan I. 2013 *Evolution of a Habitable World* (2nd edn). Cambridge University Press (hardback ISBN 978-0-52185-001-8; 314pp; £75 / paperback 978-0-52161-519-8; £40)

When this book arrived for review and I scanned the contents my first thought was, "This looks like a great asset to my current OU studies..." and by and large I have to say it has been a good companion. I found the book generally well structured and easy enough to read with the exception of the first two chapters, which seemed to ramble and wander a bit — not enough to confuse, but enough to be annoying.

After the first two chapters the book got to the point with a brief introduction to some of the methods and techniques used to discover the necessary facts and figures about the Earth and the Solar System, covering the usual culprits such as spectroscopy, radiocarbon dating and radioisotope dating. Perhaps these were a bit too brief, but with more coverage on these topics the book would have been huge and even more expensive. The rest of the book is structured as a time-line from the formation of the Solar System to the present day Earth, running through the evolution of the Hadean planet and the construction of the atmosphere to the coming of life at the end of this era and on to complex life through time and ending with the dominance of mammals after the Cretaceous/Tertiary mass extinction event.

There are quite a few words spent dealing with the mechanics of life and the possibilities of life on other planets, particularly Mars and Venus — perhaps too much time. Equally, a long section describes the Cretaceous/Tertiary mass extinction, which, while important to us mammals, was not the worst mass extinction in the Phanerozoic by any stretch of the imagination. Although these planets, and the other places in the Solar System, where life is possible are important, I would have thought a brief mention of the possibility would have been adequate, rather than a whole chapter.

This time-line is topped off by a look at global warming and then by a speculation on the future of our planet, which is less a less rigorous and, I think, unnecessary diversion.

The colour section, while nice to have, is not, in my opinion, strictly necessary as the diagrams in the book, although in black and white, are clear and in the most part concise. In fact, if you are going to have colour in the book, colour in some of the diagrams would have perhaps been a better choice.

Although, as mentioned, I do like this book, there were several irksome things about it. First and foremost is the lack of a glossary. Although most of the terms are explained in the text, I think this practice muddles things up a bit. It is nice to have a reference of all of the 'technical' terms in one place. Second is the lack of obvious answers to the quiz questions that appear at the end of each chapter. It took me quite a while — in fact it was an observation by my daughter — to discover the link to the website on the back cover, this should have been more prominently displayed.

Other than these couple of points and a few, sometimes amusing, typographical errors, I enjoyed this book more than a little.

— David Swain

A coal merchant, a quarry, a railway, tileworks and two actresses

Philip Clark

Introductiion

A well-known feature of Bromyard in north-east Herefordshire from the late 19th to the late 20th century was the tile and brick works at Linton, just outside the town on what is now the A44 (Fig. 1). They were started about 1876 by William Finney, who ran the works until 1881; but there is a considerable back story, as Finney hoped originally for a very different enterprise — a profitable stone quarry on the Bromyard Downs (Fig. 2).

Figure 1 The Linton Tile Works at the Stream Hall quarry.

The quarry report authors

In the archives of the Bromyard and District Local History Society is a remarkable manuscript document entitled and dated 'Westminster April 2nd 1873'. In it, George Berkley and Samuel Trickett announce, "As requested we have visited and made a careful examination of the Quarries and Quarry Lands (60 to 70 acres) situate on the Bromyard Downs and Stream Hall Estates in Herefordshire." I have very grave doubts of the truth of this statement. George Berkley (1821–93) was a civil engineer, a railway specialist, who as a young man was in the Westminster office of Robert Stephenson. He designed various railways in England and abroad and was president of the Institution of Civil Engineers from 1891 to 1892.[1] I can find no special knowledge that he had of geology or of quarries, although his brother was a long-standing member of the Geological Society of London.[2] His connection with Samuel Trickett is likely to be that Trickett supplied him with stone for the abutments of bridges and other purposes.

Why do I doubt that Trickett visited the Bromyard Downs? Precisely because Trickett (1820–88), a Yorkshireman, knew a great deal about stone. He had been born in Leeds and went to London as a young man, working first as agent for stone merchants at the Victoria Stone Wharf, which had a river frontage at the southern end of the Isle of Dogs. Soon he was in business there on his own.[3] In 1862 he exhibited "Specimens of stones, granite, and marble, for building, paving, and monumental purposes" at the London Exhibition.[4] In Laxton's Building Price Book of 1868 he is described as a "Quarry Owner" (this was a quarry at Horsforth, near Leeds),[5] and was able to supply many kinds of the most important building stones from Yorkshire and elsewhere. So how could he have said in the report to Finney that "The buildings in the neighbourhood said to be built of this stone prove it to be a good weather-stone [i.e. weathers well] similar in color [*sic*] and character to the Spinkwell stone quarried at Bradford, Yorkshire, which has just been used in building the New Town Hall at Manchester and was selected by Mr Street as one of the Stones for the New Law Courts in London", and that on the smaller Stream Hall estate "we believe you will find there Paving and Landings fully equal to the best Stone in Bradford or Halifax"? It is true that practical stone workers do not always have accurate geological knowledge, but the differences in facies and so in building stone quality between the Lower Old Red Sandstone of the Bromyard area and the Carboniferous Millstone Grit rocks of Yorkshire must have been pretty obvious to someone with Trickett's experience of stone. Trickett himself became a member of the Geological Society in 1876.[6] It was certainly known by the 1870s that the ORS rocks were considerably older than the great Millstone Grit and later Carboniferous building stones, even though the precise dates we now know were still unknown. I suspect that Trickett sent down a young man or two to have a look, wrote the report up in as glowing terms as possible, and got Berkley with his Westminster office to put his name to the report for respectability.

I imagine that it was Trickett whom Finney approached, rather than Berkley, because there is a probable link between Finney and Trickett. A "Mr. Trickett" spoke at the annual general meeting of the Worcester, Bromyard, and Leominster Railway in

Figure 2 The Stream Hall Quarry, showing that some good building stone was in fact quarried (photograph by Philip Clark).

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October 1872, on behalf of the contractor and explaining the delays.[7] As we shall see, Finney was a director of this rather ill-starred railway project.

The report is most enthusiastic about the potentialities of both the Downs and Stream Hall, and clearly written by someone who knew about quarries and their economics. The opening words show the general tenor of the report:

"Bromyard Downs Estate We are of opinion from the dip and strike of the Stone and from the apparent conformability of the Strata as shewn in the several openings made by you that you will find under those openings the whole of the valuable beds of stone which are expected in the vertical section at the other Quarry on the adjoining part of the Downs separated from your property by the Turnpike road."

The estate

These opening words immediately raise problems, because it does not appear that Finney actually owned "the Bromyard Downs Estate". The only references to Finney in the local directories are in 1876 when he described among the gentlemen of the neighbourhood as of "The Downs" and 1879 as of "Bromyard Downs", Norton.[8] There seem to be no surviving documents, certainly not in the archives of the Bromyard and District Local History Society, nor references in the local papers, to Finney's purchase of this land, some time before April 1873 when he received this report. There are odd references to accounts by or to Finney in the Bromyard archives between 1877 and 1880, one from John Millichap for boots and shoes in 1877–9 referring to him as of "Down Villa". Whichever this house was, now presumably renamed, he did not even own that. He seems to have rented "Down Villa", "pleasantly situated on the side of the Bromyard Downs", from March 1873. It was a substantial six-bedroom house, with considerable outbuildings, a cottage, and about six acres of pasture land. It was clearly part of the large Brockhampton estate. It is not even clear which is the "turnpike road" referred to in the quarry report. Is it the Bromyard to Worcester road, frequently called "the turnpike road", or the road across the Downs to the Stourport road with the turnpike cottage on it?

But did he ever acquire the 60 to 70 acres, including Stream Hall, as the report suggests? There is no doubt about the smaller portion. In May 1872 the "valuable freehold property" "near the town of Bromyard" "called Stream Hall" was to be sold at auction at the Queen's Arms. It included a "Drink-House, Stable, Cow-House and Garden and 5 pieces or parcels of Meadow, Orchard, Arable Land, containing 8 acres or thereabouts with … QUARRY thereon and the Right to Pasture on the Bromyard Downs".[9] It was alongside "the Turnpike Road leading to Worcester". This parcel of land was undoubtedly bought by Finney.

Then the next month two large sales of property were advertised. One was the Buckenhill Estate which had been owned by the late Edmund Higginson of Saltmarshe Castle and whose "lands open upon the fine, bold healthy downs" (which Higginson and his cousin Barneby Lutley of Brockhampton had unsuccessfully tried to enclose in 1860).[10] The other, also previously owned by Higginson, comprised 11 lots in and around Bromyard, two of the lots containing in total four cottages on the Downs "with Gardens and productive Orchards and Meadow Land" (of unspecified size).[11] There was no mention in the advertisement of the possibility of quarrying on any of the land. By July 12 the 11 lots were all "sold to the purchaser of the Buckenhill estate" (Richard Phipps).[12] Finney does not actually seem to have acquired any of the Downs property, 60 or more acres of which Berkley and Trickett reported about to him the following April. The report into the possibilities of the quarry was very detailed, as we shall see. Even if Finney was just hoping to work it on behalf of the Lord of the Manor, the Bishop of Hereford (it is obscure who was the *owner* of this common land), the report must have been music in the ears of this enterprising coal owner and railway director when they showed this interest in this land at Bromyard.

The client

William Finney was born in Richmond, Surrey, on January 2 1834,[13] son of Stephen Finney, "steward", and is wife Harriet. By 1843 Stephen Finney is "carrying on business under the firm of Oaten and Finney, Coal Merchants" of No. 12 Wharf South, Paddington.[14] In November 1857 William married at St James, Paddington, Fanny May McArthur, daughter of a "merchant"; he was living in Park Place Villas, handy for the business, and described himself as "gentleman". In the 1861 census he is taken down a peg socially, being relegated to being a "coal merchant's clerk", presumably in his father's firm, living in Ealing — but still handy for Paddington — with his wife and small daughter Emily. Stephen retired in 1864 from "Finney, Seal, and Co".[15] William continued to work for this firm as one of the partners. He and his family — by then there were two daughters) — are not traceable in the census for 1871. However, in a notice about the relations of the projected Worcester, Bromyard and Leominster Railway, with the Great Western Railway, his address in August 1871 is given as the fairly posh 3 Lancaster Street, Hyde Park.[16]

His connection with Bromyard seems to have come about through that railway. By August 1871 he was a director of the railway company.[17] In April 1872 he is explaining at the half yearly meeting why there had been so many delays in building the line.[18] In 1874 the contractor to the railway company, Joseph Yeomans, went bankrupt — and Finney had stood guarantor for him. He consequently went bankrupt himself, but the next year narrowly escaped by paying a dividend of two shillings and threepence in the pound and assigning to his Trustees his claim against the estate of Joseph Yeomans.[19] As so often with bankruptcies, the result provides us with invaluable information — namely that he was "late of No. 1, Coal Exchange, Lower Thames-street, in the city of London, Coal Merchant, Dealer and Chapman, carrying on business there with divers other persons under the name of Finney, Seal, and Company, and lately residing at Formosa, near Cookham, in the county of Berks".[20] He had in fact retired from that firm and from another business that he ran in the New Year "in favour of his father".[21] Apparently on January 14 he went to the south of France, allegedly for health reasons, but really to avoid paying all his creditors.[22] He had become involved "in transactions of a very heavy pecuniary character" not only with Yeomans but also with a Mr W. Lovel, of Malton, Yorkshire. Various creditors were after him for about £50,000, including the Worcester branch of the Stourbridge and Kidderminster Bank.[23] A dividend was first advertised in May 1875.[24] Somehow, by November Finney had succeeded in having the bankruptcy annulled.[25]

When the railway finally reached Bromyard in October 1877 there were enormous celebrations for this long-delayed project

(even though it was to be years before it finally connected through to Leominster). At the grand luncheon speeches were made, one by a Mr James Jenks, who said, "The line has been unfortunate in some respects and he saw one gentleman in the room, Mr Finney, who was made to some extent the victim of his own honourable heart. He hoped that Mr Finney was in a fair way to reap a reward for what he did, and in the development of his mine [*sic*] find a considerable amount of return." [Applause].[26] This is a clear reference both to Finney's difficulties over his support for Yeomans, and to his new quarry — did Jenks say 'mine' because he knew of Finney's profession?

Whether Finney ever exploited the quarry on Bromyard Downs I am not sure. It was the Stream Hall Quarry that was lauded by the county directory of 1876, using words similar to the quarry report of 1873: "The Stream hall property in this township [Linton], now owned by W. Finney, Esq., contains some most valuable beds of stone quite different in character from any in the neighbourhood, but exactly similar in colour, hardness, and general characteristics to the famed stone of Yorkshire. The slabs can be got in any size that can be used. When the railway now in course of construction is completed, the quarry will be placed in connection with the large towns of England, which are greatly in need of this kind of stone."[27]

There are, as can be seen by looking across the lake now occupying the quarry, beds of the same St Maughans sandstone as elsewhere on the Downs, exploited at some stage in the quarry's history. But Finney seems to have decided in 1876 (if not earlier) that the mudstone from Stream Quarry was more suitable for bricks and tiles than for building stone, because in that year a Bromyard resident, James Walwyn, was brought before the magistrates for allowing his son, who was aged less than 12, to work 12 hours a day or more at the brickyard, and not to attend school.[28] The magistrates decided, to the annoyance of the factory inspector, that Walwyn had not known of the law, or, probably, that his son worked such long hours! In 1877 Finney got a license for the use of a kiln constructed by Messrs Wedekind, 158 Fenchurch Street, London, and H. Chamberlain, Barnsley, for burning bricks.[29] The railway siding on the north side of the turnpike road was constructed in October 1878 "to accommodate Mr Lutley and Mr Finney".[30] Perhaps this implies a partnership between Lutley, the big landowner of Brockhampton and of the enclosed portions of the Downs, and Finney.

How soon did things go wrong with Finney's enterprise at Stream Hall? In March 1881 at the census Finney was not living with his wife and daughters, who do not appear anywhere in the country. He was lodging with a well-known town tradesman and his family in Bromyard, still described as "sole master employing about 25 hands".[31] But he went bankrupt later in the year, now described (rather brutally) as "of no occupation" in November.[32] He died in Tunbridge [Wells?] in 1890, aged 56. His widow Fanny lived until 1916, dying at 84.

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A curious postscript, linking Bromyard to a more exotic world, is that both of the Finneys' two daughters became successful actresses. Emily May, born in 1859, was, after her father's bankruptcy, "almost the sole support of her mother and younger sister". It is alleged that she took up acting for this purpose;[33] and certainly she was taken on by Gilbert and Sullivan for Patience in

Figure 3 May Fortescue.

April 1881, originating the role of Lady Ella. She called herself 'Miss Fortescue', and in 1882 appeared in the first production of Iolanthe. Like many actresses of the time she was taken up by 'society' and in 1882 caught the eye of a Sandhurst cadet, Lord Garmoyle, the eldest son of Earl Cairns, who had been Lord Chancellor. Garmoyle proposed to her in July 1883 and was accepted, and his parents welcomed her to their home. But the next year he jilted her, allegedly under pressure from his parents, or perhaps from his friends. She brought an action for breach of promise, which was attended eagerly by crowds of people, and reported in newspapers all around the country. Lord Garmoyle paid her off with the unprecedented sum of £10,000.[34] With the money, as 'May Fortescue' (Fig. 3), she founded her own theatre company, which toured for many years and frequently performed the works of W. S. Gilbert (the straight plays without Sullivan's music). She never married, but acted until 1926, dying at 92 in 1950.

Helen Maud, born some 10 years later, also became an actress, calling herself 'Helen Ferrers' (Fig. 4). On at least one occasion, in Dublin in the 19th century, the sisters acted together.[35] Helen married, in 1906, another actor, Eugène François Mayeur, who died in 1918 having given her one daughter, Mary Helen. Helen Ferrers Mayeur, as she liked to be known officially, lived with her daughter in west London in the 1930s and took part in 20 films between 1931 and 1935. She died in 1943. Mary Helen Mayeur nursed at St James Hospital, Battersea in the late 1930s and died, unmarried, in Surrey in 1988, the last descendant of William Finney.

Figure 4 Helen Ferrers.

The quarry

What of quarrying on the Bromyard Downs? It had certainly been carried on in a small way for some time in both the mudstone and the sandstone beds, which alternate in what are now called the St Maughans Formation of the Lower Devonian (previously known as Dittonian). The Strategic Stone Study — a building stone atlas of Herefordshire (2012) comments that "the mudstones have been used for brick-making. The sandstone bands, meanwhile, have been quarried for flagstone and, where thick enough, for dimension stone". In fact, as a glance round Bromyard will show, the mudstones and sandstones have been used extensively over some centuries for not very high-class building stone.

There are scattered references to quarries on the Downs in local papers of the 1850s, and when in 1866 there was a proposal to enclose Bromyard Downs, bitterly opposed by many local inhabitants, the Assistant Enclosure Commissioner remarked that he had seen some stone quarries on the Downs, and asked whether they were worked by the Bishop of Hereford (the Lord of the Manors of Bromyard and of Norton). The answer was that they were.[36] In 1879 a directory asserted, "on the Downs, … are stone quarries".[37]

But the quarry report was envisaging far larger operations. It continues with the advantages of the site, on the slope so with good drainage and sites for debris, and praising the "Quantity and Quality of Stone … abundant, practically inexhaustible and we estimate that you may have 50 or possibly 100 feet of good workable stone, consisting of Building Stone, Large Landing[38] and Flags, Step Blocks and Blocks to saw into Slabs suitable for Halls of Mansions and Public buildings, for general paving, sinks, sills, copings, quoins wall stones &c. The top beds which in most Quarries are merely rag and thrown over the tip as debris appears in these quarries to consist of an useful building stone suitable for local purposes. All the lower beds in the Quarry referred to, are either suitable for Landings &c or are a high class durable building stone of uniform and good colour …".[39] Markets were abundant, demand for stone being "far in advance of the supply — you will therefore have no difficulty whatever in finding a market for the whole of the Stone that you can produce. The upper beds referred to will find a ready sale in the Towns of Worcester, Birmingham, Hereford, Gloucester, Oxford, Wolverhampton &c and leave a good margin of profit beyond working expenses. The lower beds or best stone will be in demand and find a ready sale in the Towns referred to and in the whole of the Southern Towns including London, for in addition to the Law Courts already named there are a great many other buildings about to be erected, that will require large quantities of Landings, Steps, Blocks, Sawn Slabs and Pavings." Transporting the stone, always a high part of the cost of heavy items, would present no problems: "When the Worcester and Bromyard Railway now nearly completed to Yearsett is open all the markets above referred to will be easy of access to these Quarries and an advantage over the Yorkshire Stone in the cost of transit of from 2/ to 6/ per ton or say for the great bulk of the Stone an average of about 4/ a ton may be fairly calculated on."

If Finney cared to "let or sett" the quarries he could look to "a Royalty of about 5/- per yard of surface or say £1100 per acre or at about 8d per ton upon all stone sent away". If he decided to work the quarries himself he might employ "300 men and boys" who "would produce about 36000 tons a year". These could be sold for £56,100, made up in order of value of Pavings, Best block, Steps, Wall stones, Top block, Landings, Copings Sinks & Sills. It would cost him £18,000 in wages, £15,800 in Freight and Cartage, £2,000 for Baring, Trams, Repairs of Tools, £1,500 for Management, and £700 for Depreciation of Plant & Tools — a total of £38,000, or adding 20% for contingencies, £45,600. Finney was thus looking at a profit of £10,500 a year — but would need "a working capital of about £20,000" to achieve this — £8,500 for Plant and Machinery, £6,000 for Working Capital, £2,000 for Cottages for Men, £1,500 for Horses and Stables, plus 10% for contingencies.

"We would advise you immediately to put up proper appliances and quarry through the entire depth of the Stone making an opening sufficiently large, say about 30 feet by 40 feet. This would prove the horizontal size of the Posts and give a vertical section of the depth of each of the beds."

As said earlier, it is doubtful if Finney ever exploited the quarry on Bromyard Downs. Later attempts were made, though. Today there are the visible remains of smallish, perhaps exploratory, quarrying in various places on the Downs. Some of these are probably the earlier, small-scale enterprises referred to above. But there there is the large vertical face and pit west of the road across the face of the Downs, above Quarry Cottages and Quarry Farm. That is prominent on the 6in to the mile Ordnance Survey map of 1884–5, drawn as if it were in operation, as I think it was. And there is the large quarry south of the Worcester road, now a caravan park, which may have been exploited as late as 1939.

No quarry owner is listed in the 1885 directory (or earlier), but in 1890 the Rouse brothers of New Road, Bromyard, are "Proprietors of the Down Stone Quarry". They were jacks of all trades — "builders and contractors, steam saw mills, engineering and for timber merchants, brick manufacturers, dealers in all kinds of building materials, stone and marble masons, wheelwrights and general smiths".[40] They had added the quarry to the portfolio of occupations they had advertised in 1885, although in compensation they were no longer "coal and lime merchants" as well. But by 1891 they seemed to have dropped the quarrying (and by 1900 they were just builders). The Linton brick and tile works remained William Finney's longest running contribution to the economy of Bromyard.

Endnotes

1 *Grace's Guide to British Industrial History*, http://www.graces-guide.co.uk/George_Berkley
2 Personal communication, archivist Geol. Soc.
3 'The Isle of Dogs: Introduction', *Survey of London: vols 43 and 44: Poplar, Blackwall and Isle of Dogs* (1994), 514–18. URL: http://www.british-history.ac.uk/report.aspx?compid=46507
4 *Catalogue of London Exhibition* 1862: Class I.
5 'Quarry owners, Horsforth, near Leeds' in *Catalogue of London Exhibition 1862*, supplying Bramley Fall stone (the Millstone Grit which had built the Euston Arch, from a quarry a few miles south of Horsforth). The Bramley Fall Stone which was quarried at Horsforth in Leeds from the Rough Rock acquired an enviable reputation for strength and durability and was widely used in bridge and dockyard construction in London and elsewhere.
6 Personal communication, archivist Geol. Soc.
7 *Worcester Chronicle* 2.10.72
8 *Littlebury's Directory* 1876; *Kelly's Directory* 1879
9 Document in BDLHS archives A 56/1 Nb

10 *Berrow's Worcester Journal* May 26 and October 6, 1866
11 *The Bristol Mercury* June 15 and 29, 1872
12 *The Bristol Mercury* July 20, 1872
13 Parish registers of St Mary Magdalene church, Richmond; living "under the hill" (like a hobbit?)
14 *London Gazette* 16.3.43
15 *London Gazette* December 2, 1864
16 *Daily News* 17 August 1871
17 *Daily News* 17 August 1871; Worcester Chronicle, 4 October 1871
18 *Worcester Chronicle* 6 April 1872
19 *Worcester Chronicle* 9 May 1874 and 1 August 1874; *London Gazette* July 2, 1875
20 *London Gazette* 8 May 1874. The Formosa group of houses in Cookham had different occupants in the 1871 census.
21 *London Gazette* 6 January 1874
22 *The Standard* 2 May 1874
23 *Leeds Mercury* 4 May 1874
24 *The Standard* 8 May 1874
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27 *Littlebury's Directory* 1876
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31 Census 1881
32 *London Gazette* 11 November 1881
33 Wikipedia article 'May Fortescue'
34 *Spectator* 22 November 1884
35 "Miss Fortescue made a decided hit in the dramatic version of Ouida's Moths, in which Miss Ferrers appeared as the Countess." Ramsay Colles, *In Castle and Courthouse, being reminiscences of thirty years in Irelan*d.
36 *Berrow's Worcester Journal* 26 May and 6 October 1866
37 *Kelly's Directory* 1879
38 Landings 'Stone used in or suitable for the construction of staircase landings'. *New English Dictionary*, vol. VI, Oxford 1908
39 This a subsequent quotations are from the quarry report.
40 Quotations in this paragraph: *Kelly's Directory* 1885, 1890, 1891, 1895 and 1900

OUGS
Moyra Eldridge Photographic Competition 2013
Winning and Highly Commended photographs for 2013
Presented at the OUGS AGM, 6 April 2013 at the University of Chester

Geologically Inspired Landscape, Winner — Bob Morley

Travertine terraces — Mammoth Hot Springs, Yellowstone NP

Travertine terraces — Mammoth Hot Springs, Yellowstone NP. The thermal springs in Yellowstone NP are formed by meteoric water heated underground by the underlying magma body. Most of these springs (e.g. those which give rise to the well known geysers) have dissolved silica from the underlying igneous rocks, but at Mammoth Springs the hot water has run through limestone and the rapid precipitation of dissolved calcium carbonate forms travertine. Algae living in the warm pools have tinted the travertine shades of brown, orange, red and green. More than two tons of travertine flow into Mammoth each day in solution. Minor earthquakes reroute the flow from time to time and it often engulfs trees and bushes.

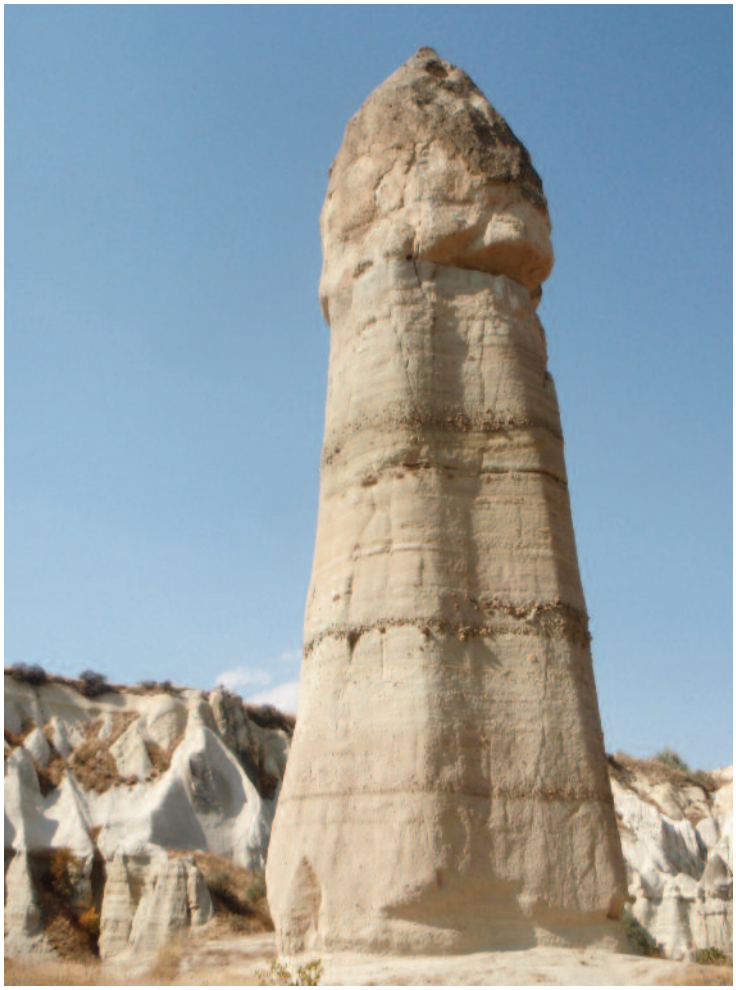
Geologically Inspired Landscape, Highly Commended — Greg Artis

Ben Loyal, Sutherland

Geological Feature or Structure, Winner — Bob Morley

Conchoidal Fractures in Rhyolite, Laugahraun, Iceland

The dome on the high point of this lava field near Landamannalaugar had collapsed outwards at a late stage of the eruption to leave a petal-like arrangement of blocks marked in places with this intriguing pattern. Brittle and fine-grained materials fracture in this way and do not follow any natural planes of separation. Conchoidal fractures often result in a curved breakage surface that resembles the rippling, gradual curves of a mussel shell [the word 'conchoid' is derived from the word for this animal (Greek konche)].



Geological Feature or Structure, Highly Commended — Heidi Barnes

Fairy Chimney

Industrial Geology, Winner — Jenny Forrest

Abandoned, a derelict jetty for the pumice quarries on Santorini.

Before the advent of mass tourism the main industry on Santorini was the export of pumice. There were numerous quarries on the island using pumice from the Minoan eruption of 1600 BC: *c.* 2 million tons per year were quarried and passed down the caldera wall by a series of chutes and ramps. Santorini pumice was mixed with cement and used to line the Suez Canal during its construction from 1859 to 1869. Quarrying ended in 1986 when tourism was becoming a more important part of the economy. This photograph is of an abandoned and decaying loading ramp below the Fira quarry in the south-east of the island.

Industrial Geology, Highly Commended — Jenny Forrest

The Wine Industry – the geology is essential, La Geria, Lanzarote

Popular Vote, Winner — Linda McArdell

‘Whirlpool’ on Isla Santiago, Galapagos *(opposite)*

This pahoehoe lava flow seen at Sulivan Bay erupted in 1889, flowing from Cerro Inn, in the south east of Santiago to the coast. It still looks very recent. The lava was certainly very fluid, and therefore very hot as seen by the finely coiled ropes in the pahoehoe, and was spectacular in the shapes and patterns it made. Google Earth shows the extent of the lava field, as it flowed around several small cinder cones on the way to the sea. Santiago is very close to an offset in the constructive plate boundary and the Galapagos hotspot, which explains the character of this particular lava.

Book review

Meere, P., MacCarthy, I., Reavy, J., Allen, A., and Higgs, K. 2013 *Geology of Ireland: A Field Guide*. Cork: The Collins Press (ISBN 976-1-84889-166-1; paperback, 372pp; £17.99)

This is a marvellous guide to geology in the field in Ireland, covering the whole island. The meat of the book is the 17 field localities described in detail, mostly along the coastal belt, but with some farther inland. This follows an introduction to geological principles and how they are used to interpret what is seen in the field.

The introduction is divided into seven sections, from the Earth's composition, plate tectonics, through the three types of rock, palaeontology, lithospheric deformation, and finally the Pleistocene and its glaciations. Each section highlights the relevant fieldtrips in the second section. There are good diagrams of the classification of igneous and sedimentary rocks, and determining metamorphic facies. OU students will recognise and be familiar with these. There is an explanation of sedimentary environments, and a useful explanation and map of glacial and periglacial features in Ireland, which can be used in the areas not covered by the field trips.

The second section comprises 17 field locations, working anticlockwise around the island starting at Waterford. Each location includes a geological map, clear annotated diagrams and marked-up photographs with well-chosen and captioned photographs, and good explanations in the text. The sites include, for example, the sand volcanoes at the Bridges of Ross, the tetrapod track way at Velentia (Prof. Ken Higgs spoke about these at the Dublin OUGS 2013 Symposium, where I bought the book from him — these track ways are well worth seeing and provide an insight into the first reptiles moving onto the land).

These are a good example of the book containing the most-up-to date geological research. The field trips also include the Burren, the Dingle Peninsula, the Mourne and Wicklow mountains, the North Antrim Coast (including the Giant's Causeway) and many other iconic locations that are superb teaching (and learning) locations. The range and quality of exposures demonstrates why many of the basic geological concepts we rely on were pioneered in Ireland.

The book ends with a glossary, advice on working in the field, chronostratigraphic columns and an index.

All in all, an excellent book, one to be taken in the field and used to understand and enjoy the best of Irish geology — really a good incentive for a visit to Ireland again soon; and why we should run more OUGS fieldtrips in Ireland.

— John Lonergan, London OUGS, BSc Geosciences, FGS

Book review

Gillen, Con 2013 *Geology and Landscapes of Scotland* (2nd edn). Edinburgh: Dunedin (ISBN 978-1-78046-009-3; paperback, 246pp; £24.99)

When I saw that Con Gillen had produced a second edition of his Geology and Landscapes of Scotland I was very excited and keen to review it. I visit Scotland regularly and had found that the first edition, which was in the OUGS library, very helpful on several occasions. The book is smaller than A4, well produced and lovely to look at. However, at 800g it may not be what you would carry in your rucksack! Also, the paper is glossy, which shows off the photos well but, depending on where your light source is, may affect readability, which is a shame. There are many good photographs, clear diagrams appropriate to the text and some maps.

The book is divided into nine chapters, one Appendix, a fairly comprehensive Glossary of Technical Terms, a Bibliography, two indices (one general and one of place names) and a list of Gaelic terms. This last is a first for me and extremely helpful for my hill/mountain walking, not just for geology. Thank-you Con for helping educate we Sassenachs!

Chapter 1 gives an introduction to the science of 'geology' for the beginner. Con, in his introduction, suggests that those who already have basic knowledge skip this chapter. He has managed to include the basics into 25 pages clearly, succinctly and in a well-illustrated manner, although I would have liked to see a diagram of the Rock Cycle, as this would have been helpful for non-earth scientists.

Chapter 2 gives a whistle-stop summary of the main elements of the geology of Scotland (e.g. Lewisian, Dalradian, the Caledonian orogeny) as a precursor to more detail in the succeeding chapters. The next six chapters look at each of the areas into which Con has divided Scotland into greater geological/landscape detail. Where appropriate, within each chapter, more technical information is given — for example 'Age Dating of Rocks' and 'How Coal Forms'.

Finally, Chapter 9 covers 'Natural Resources, People and Landscape'. This investigates what constitutes a natural resource, how useful minerals form and why they are found in particular settings. The 'actual' resources have been dealt with in previous chapters. Con finishes with a summary of how the natural resources have influenced the landscape and how this, in turn, has influenced the people and vice versa. A thought-provoking finish to a fascinating book, which is an excellent addition to my Scottish geology library.

— Jane Michael BSc (Hons) (Open)

The Tywi Drainage Basin, Carmarthenshire: some aspects of its geology and geomorphology

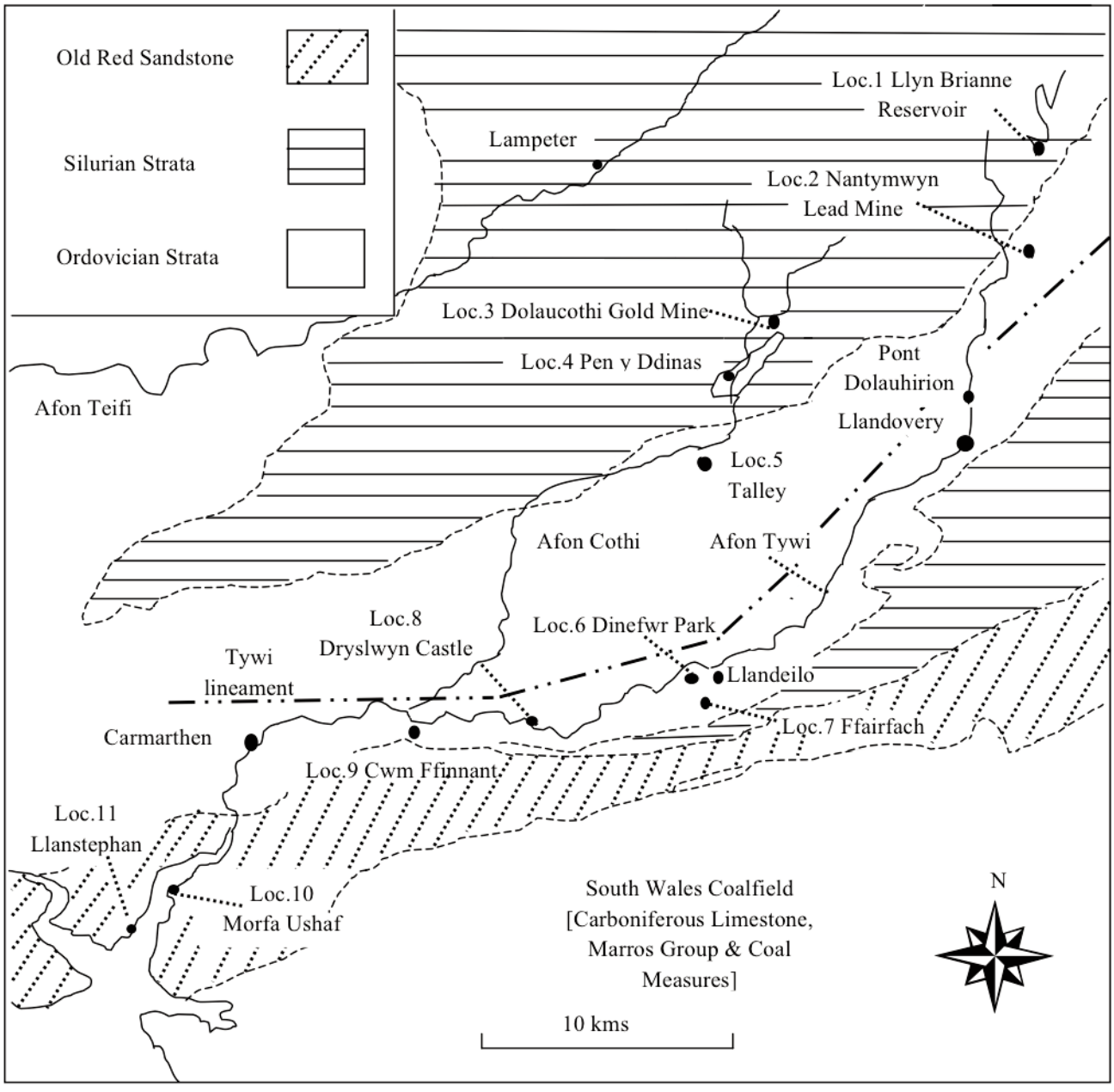
John Downes (jd1936@btinternet.com)

Introduction

The headwaters of the Afon Tywi drain the rugged dissected upland on the borders of Powys and Ceredigion. The river then flows southward through extensive coniferous plantations into the Llyn Brianne Reservoir, which is retained behind a massive earth and rock dam. Below Rhandirmwyn, the valley begins to widen and then follows a meandering course across a broad alluvial flood plain through Llandovery, Llandeilo and Carmarthen (Fig. 1). The Afon Cothi is a major northern tributary stream, flowing roughly parallel to the Lower Tywi, which it joins near Carmarthen. Both rivers follow the structural trend of the great fold/fault belt known as Tywi lineament, which is aligned NE–SW. This major structure, developed within Ordovician and Silurian strata, was uplifted, folded and faulted at the end of the Caledonian Orogeny (Acadian phase). The faulted crushed rocks within the Tywi lineament are riddled with vein quartz and in some localities there are hydrothermal ores of galena, zinc blende and chalcopyrite. Near Pumsaint in the Upper Cothi Valley, the Romans are known to have worked a weathered quartz saddle reef exposed on the surface, where gold occurred in association with sulphides of iron and arsenic.

In the Llandeilo-Carmarthen area, the Ordovician rocks formed during early Arenig times are generally coarse-grained sandstones and conglomerates interbedded with mudstones that contain a variety of neritic trilobites and brachiopods, which demonstrates a relatively shallow marine environment of deposition on

Figure 1 Map of the geology of the Tywi Drainage Basin.



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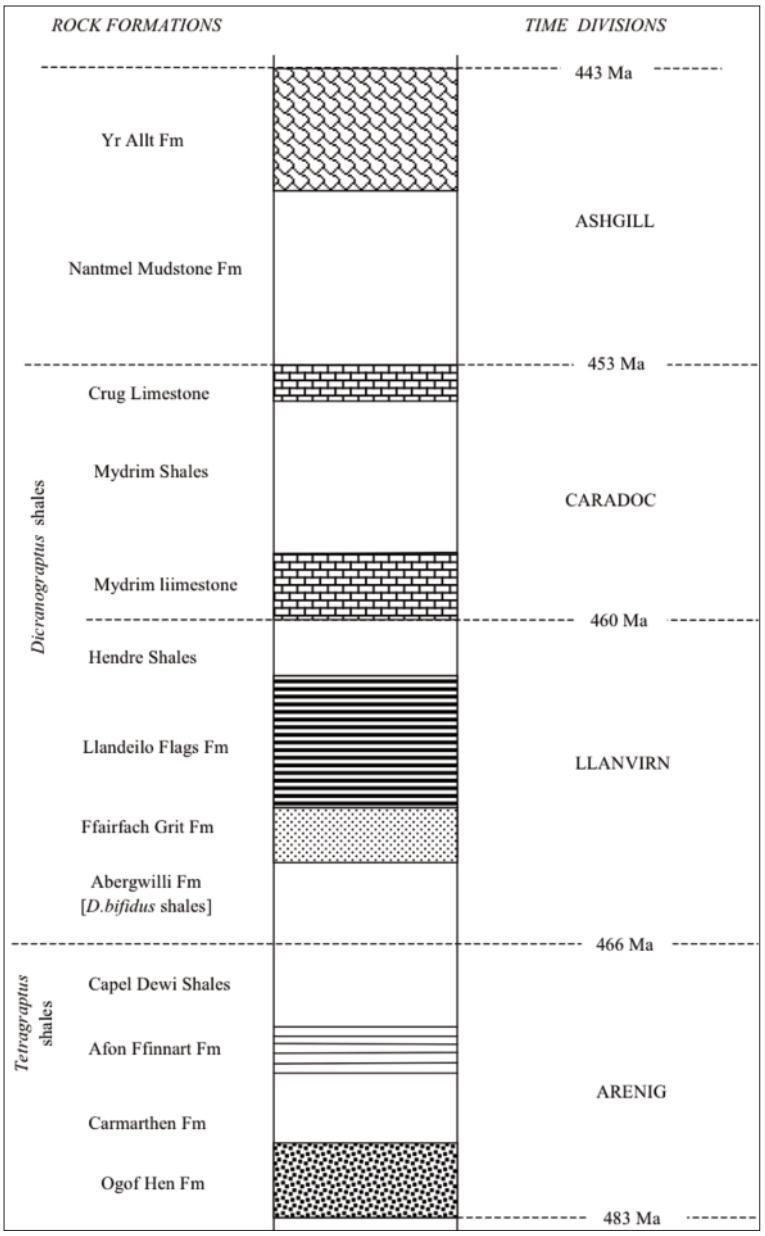
the margins of the Welsh Basin (Fig. 2). Later, finer-grained sediments predominate; these mudstones and turbidites, belonging to the Afon Ffinnant Formation and formerly known as the *Tetragraptus* Shales, were deposited in the deeper waters of the basin. The shales have yielded graptolites (such as *Tetragraptus* with four branches) that were pelagic organisms, drifting across the seas of the Welsh Basin. When the graptolites died they sank into the sea floor muds, where they were preserved under anaerobic conditions. By Llanvirn times there were great thicknesses of mudstones deposited in the Welsh Basin and the characteristic 'tuning fork' graptolites of the genus *Didymograptus* were common. The Llandeilo Flags appear to have been laid down in shallow waters on the margins of the Welsh Basin. Trilobites were abundant at this time, including *Trinucleus* with its ornamented head shield, and the rounded form of *Ogygiocaris*. Shallow marine sedimentation continued during Caradoc times, when shelly limestones and calcareous mudstones were deposited within the *Dicranograptus* shale sequence. Finally, turbidite sandstones and conglomerates are increasingly dominant in the mudstones at the top of the Ordovician sequence (Ashgill Series), which suggests an increased sediment supply into the Welsh Basin from surrounding land areas.

Figure 2 Stratigraphical column for the Ordovician rocks of the Tywi Valley above Carmarthen.



The following localities provide an insight into the geology of the Tywi Valley, although it must be stressed that much of the area is intensively cultivated or under woodland and so there are only limited exposures of the underlying rocks.

1. Llyn Brianne Reservoir (SN795484)

It is well worth exploring the upper stretches of the Tywi, although after leaving Llandovery you need to drive with care along the narrow road that winds up the valley for about 15km to the dam at the southern end of the Llyn Brianne reservoir (Fig. 3). There are car parking and toilet facilities adjacent to the spillway. The dam was completed in 1972, thus providing a means of regulating the seasonal fluctuations in the flow of the river in order to support water abstraction downstream at Nantgaredig near Carmarthen. The choice of this site for a large reservoir was influenced by several factors. Firstly, the bedrock here is formed mostly of impervious Silurian mudstones (Llandovery Series), hence seepage from the reservoir is minimum. Secondly, the narrow V-shaped valley could be dammed relatively easily using locally quarried rock and boulder clay. The dam is 91m high and only about 300m wide. Thirdly, the area is sparsely populated, thus minimizing re-housing and compensation costs. This is an area of high annual rainfall and rapid slope erosion, hence many of the valley sides have been planted with quick-growing coniferous trees in order to absorb run off and prevent excessive silting of the reservoir (Fig. 4, *opposite*).

Figure 3 Map of Lynn Brianne.

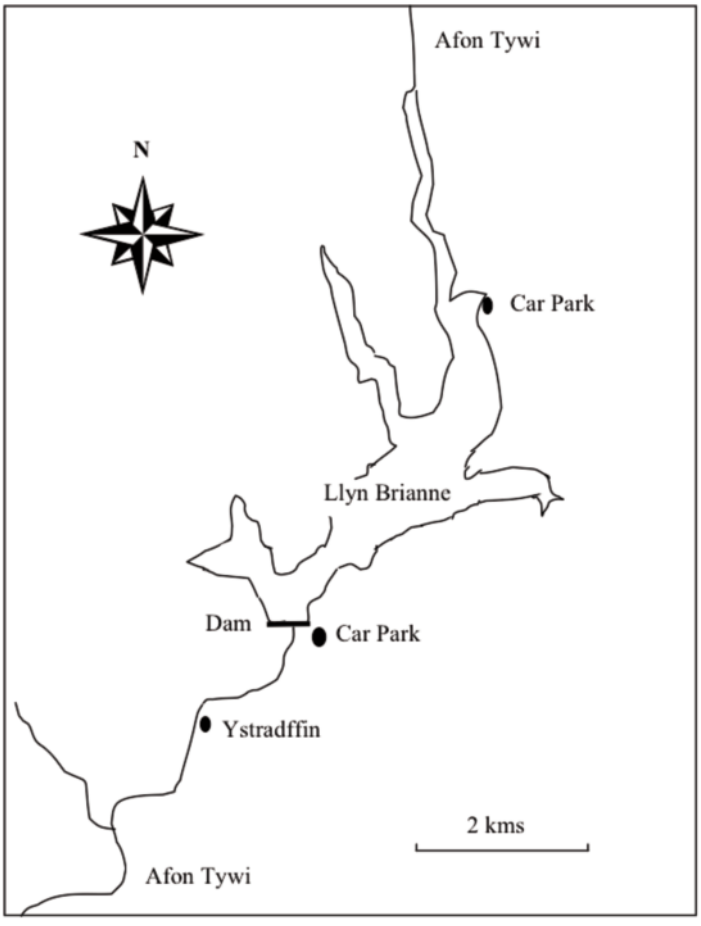


Figure 4 View looking north across Lynn Brianne (photograph by Geoffrey Davis).

Figure 6 Pont Dolauhirion on the Afon Tywi.(photograph by Roy Fellows).

2. Nantymwyn Lead Mine (SN787445)

After leaving Llyn Brianne, drive down the valley to the village of Rhandirmwyn. Here you can get refreshment at the Royal Oak Inn, which was originally built as a hunting lodge in the 1850s. The crags and caves above the nearby Tywi Gorge were the domain of the infamous 16th-century highwayman known as Twm-Shon-Catti, who appears to have been something of a Welsh Robin Hood. Records show that up to 400 men were employed in the local lead mines in 1791 and mining continued spasmodically up until the 1930s. Today many of the old mines have collapsed and been infilled, but there are several spoil heaps where samples of galena, zinc blende and chalcopyrite can be found. Follow the track from Nant-y-Bai (SN775445) on the main road to the site of the Nantymwyn Mine where the remains of the Angred shaft engine house and chimney still stand (Fig. 5). Geologically, the metallic ores occur within quartz veins that cut through the faulted mudstones of Ordovician age (Ashgill Series). The minerals were originally precipitated by hot hydrothermal fluids rising through the crushed and folded rocks that follow the NE–SW trend of the Tywi lineament.

Continue down the valley towards Llandovery, and if you have sufficient time, it is worth stopping at Pont Dolauhirion (SN762360) where a magnificent bridge spans the Afon Tywi (Fig. 6). The bridge was built in 1773 using local stone, but it is unique in its design, having circular holes on either side of the main arch, which provide extra strength and additional relief in times of flood.

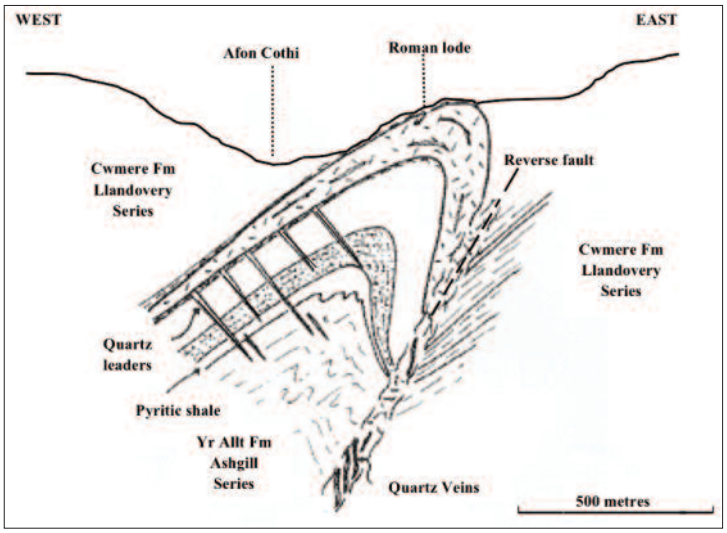
3. Dolaucothi Gold Mines (SN663403)

From Llandovery join the A40 in the direction of Llandeilo. At Llanwrda turn right on to the A482 and follow this road for about 15km to Pumsaint. The gold mines are located in the valley of the Afon Cothi to the east of the village of Pumsaint. The workings are now owned by the National Trust, which provides guided tours to the public during the tourist season. The mines date back to Roman times and they are designated as a SSSI for their archaeological, biological and geological importance.

In the Dolaucothi area, gold bearing quartz veins occur in a NE–SW trending zone of intense crumpling, where the core of a large anticline is formed of shales of the Yr Allt Formation (Ashgill Series, Ordovician) surrounded by the younger Cwmere Formation (Llandovery Series, Silurian) (Fig. 7). As uplift and folding took place at the end of the Caledonian Orogeny, hot mineralising fluids migrated upwards creating large flat lying quartz

Figure 5 Angred shaft, Nantymwyn lead mine (photograph by Geoffrey Davis).

Figure 7 Cross section through the Dolaucothi anticline.



veins known as saddle reefs connected by steep leader veins. The principal ores are iron pyrites and arsenopyrite, while small amounts of galena and zinc blende are localised along fractures. Most of the gold is associated with the arsenopyrite, which usually forms perfect, silvery rhomb-shaped crystals in both the pyritic shales and the quartz veins.

The Dolaucothi Mine was developed during the tenure of Sextus Julius Frontinus, who was the Roman governor of Britain when a fort was established at Pumsaint *c.* AD 78. Mining continued until at least the end of the 3rd century AD. The Romans made extensive use of water carried from higher up the Afon Cothi and also from the Afon Annell by aqueduct and leats to the open-caste mine workings. The method of mining used by the Romans is known as hushing and was also used in 19th century lead and tin mines. Water was stored in tanks (small reservoirs) above the site and then suddenly released, thus washing away the weathered surface material and exposing the quartz veins. Near the surface the sulphide minerals would have weathered and decomposed into oxides and clay, liberating the denser gold grains and making them retrievable from the slurry. The water was also used for operating trip hammers to crush the ore and for washing the comminuted material.

After the site was abandoned with the departure of the Romans, it was not until the 1870s that extensive underground workings were developed. Several companies successively operated the mine until 1912, when work ceased. Renewed interest in the 1930s led to the sinking of a shaft some 130m deep in an attempt to locate new lodes. Initially the ore was crushed and processed on site, but later it was sent to Antwerp for gold recovery and with the outbreak of war in 1939 the mine was finally closed. The deeper unweathered ore is difficult to treat even today, because the gold occurs in a very fine-grained form locked within sulphide crystals embedded in hard white quartz. The pulverised ore can be treated with an aerated solution of sodium cyanide in which the gold is selectively dissolved, but it is a complex and expensive process.

4. Pen y Ddinas Quarry (SN627356)

After visiting the gold mine drive back along the A482 for *c*. 2km then turn right on to the B4302 leading to Llansawel. The quarries are located *c*. 1km south-east of the village on the B4337 and were used to produce aggregate for road construction and building work. They were closed down in the late 1980s, but were partly reopened in 2007 to provide infill for the new LNG pipeline that traverses Carmarthenshire. The workings provide well exposed sections through the Yr Allt Formation (Ashgill Series), comprising a sequence of turbidite sandstones, siltstones and mudstones in the core of the Cothi anticline. This structure has a typical Caledonian trend along a NE–SW axis. The thick sandstone beds within the quarry contain numerous fissures infilled with quartz crystals precipitated from localised hydrothermal fluids. These syntectonic quartz veins are associated with regional deformation during the Acadian phase of the Caledonian Orogeny (Early- to Mid-Devonian). On the south side of the lower quarry the dark grey Yr Allt mudstones are poorly cleaved, extensively disturbed and slumped.

The sandstone beds can easily be examined in the blocks alongside the quarry road and on the floor of the lower quarry (Fig. 8). They display well-developed ripple marks, while there are sole structures on the base of some beds (Fig. 9). These include flute marks that were excavated by rapidly moving, sediment laden turbidity currents flowing down the marginal slope of the Welsh Basin during the late Ordovician. After the sands were deposited and the energy of the current began to decline, layers of silt and mud were laid down. There are load casts, which appear as gently curved bulges, and flame structures developed within the bedding. There is also evidence of soft sediment deformation in the form of slumping and sliding, which would occur under quicksand conditions before lithification. These dewatering structures reflect the occurrence of glacioeustatic regression in the Welsh Basin during the late Ordovician, when increased sediment supply and falling sea level produced slope instability, giving rise to slumped and destratified sediments.

5. Talley Abbey (SN632329)

The small village of Talley is located off the B4302 *c*. 4km south of the Pen y Ddinas Quarry. It is well known for its 12th-century abbey (a former monastery), which has stood as an imposing ruin since the Reformation. The abbey stands on a low ridge that extends SW–NE for *c.* 200m across the Talley Valley, which is cut into the underlying bedrock formed of the Yr Allt Formation. These dark mudstones and sandstones are exposed in a cutting on

Figure 8 Lower quarry at Pen y Ddinas.

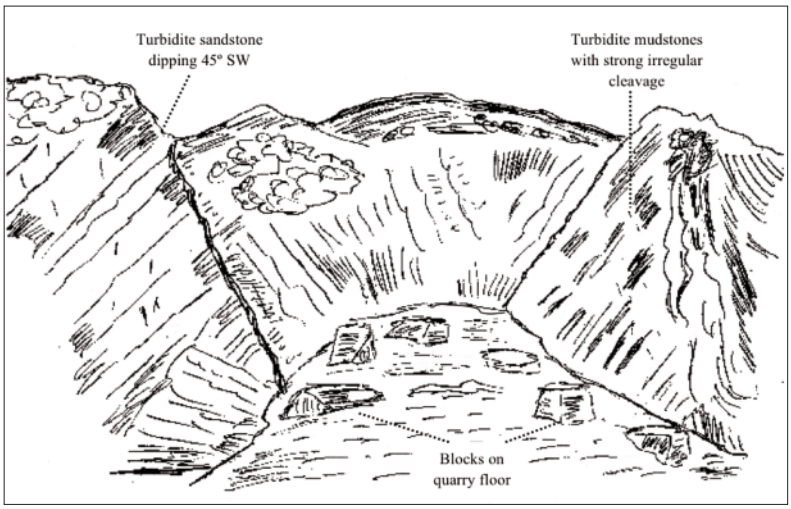


Figure 9 Sole structures on base of turbidite sandstone, Pen y Ddinas Quarry (photograph by John Downes).

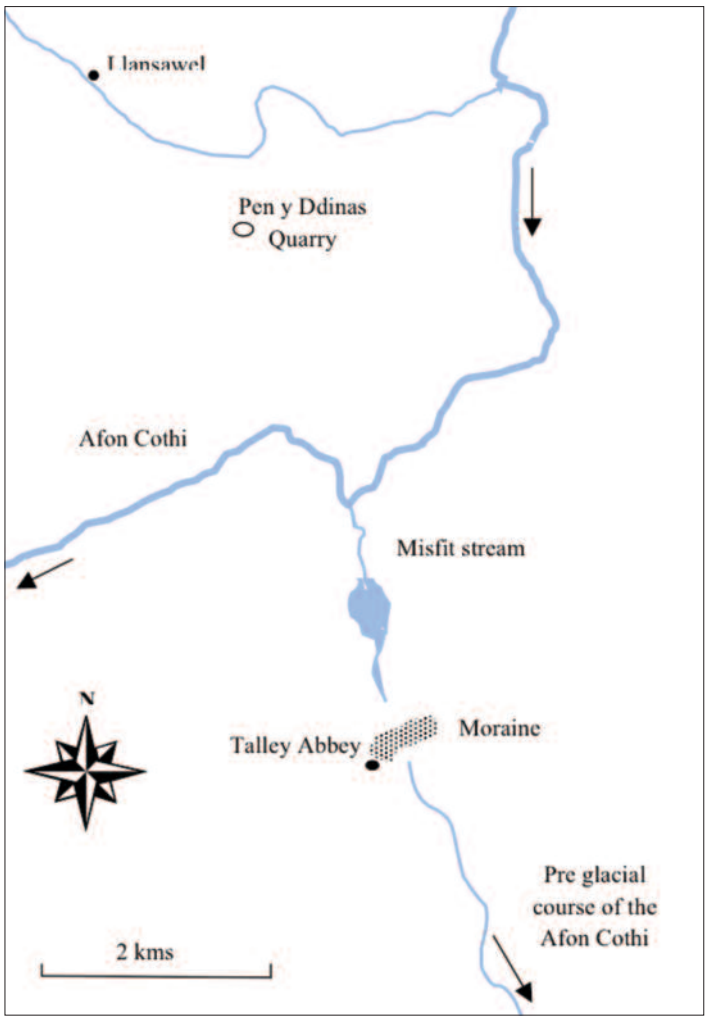


Figure 10 Glacial diversion of the Afon Cothi

the forest track at SN 629328 *c*. 500m from the abbey. The valley ridge is a significant geomorphological feature that is marked on the BGS 1:50,000 Llandovery sheet as 'hummocky glacial deposits'. These are interpreted as morainic debris deposited at the front of a glacier moving southward along the Talley Valley during the late Devensian, some 15,000 years ago. The moraine stands less than 10m above the valley floor, yet it has had a profound effect on the drainage system of the region. The pre-glacial course of the Afon Cothi would have followed a southerly route through Talley to join the Afon Tywi near Llandeilo (Fig. 10). However, as the Talley glacier retreated, leaving the morainic dam, meltwater would have built up and escaped westward cutting the present course of the Afon Cothi, which flows via Brechfa to Pont-ar-gothi near to its confluence with the Afon Tywi. The sharp V-shaped bend in the Cothi near the hamlet of Moelfre marks the point where the diversion occurred. Today the Talley moraine acts as a watershed separating the small misfit stream flowing northward from the Cilyllynfawr lakes to the Cothi and the headstreams of the Afon Dulais flowing south to join the Tywi. Thus we have a classic example of the diversion of a pre-existing drainage system resulting from the deposition of a moraine by a melting glacier.

6. Dinefwr Park (SN612217)

Dinefwr Park is located on the north bank of the Afon Tywi immediately west of Llandeilo. From the park entrance follow the signs to Newton House, where there is a car park, toilet facilities and a cafe. Walk over to Dinefwr Castle (SN612217) overlooking the Afon Tywi floodplain.

There are some good exposures of Lower Llandeilo Flags in the old quarry in Castle Wood (SN615217) and along the road near the lake (SN608223). Middle Llandeilo Flags occur along the old road near St Tyfei's Church, and a small quarry in the woods *c*. 250m north-east of Newton House exposes the Upper Llandeilo Flags. The well-bedded limestones and calcareous siltstones of this Llandeilo Flags Formation contain trilobites such as *Basilicus tyrannus, Lloydolithus lloydii* and *Ogygiocarella debuchii*, and the brachiopod *Dalmanella parva*.

7. Ffairfach Railway Cutting and Afon Cennen Section (SN628212–SN622202)

From Llandeilo follow the A476 for *c*. 1.5km to Ffairfach and park near to the level crossing adjacent to the railway station. The cutting is immediately south-west of the level crossing. The strata dip steeply to the south and consist of the Ffairfach Grit Formation overlain by the Lower Llandeilo Flags of Mid Ordovician age (Llanvirn Series). The basal quartzitic grit is *c*. 26m thick and is overlain by pebble rich cross stratified sands. These are succeeded by flagstones and grits with shale bands, some poorly exposed rhyolitic tuffs and finally conglomerate beds. An old quarry at the south-west end of the cutting exposes the basal units of the Llandeilo Flags Formation; however, much of the section is badly overgrown and difficult to access despite being designated as a SSSI.

The Afon Cennen section continues southward from the railway cutting, where an almost complete sequence of the Llandeilo Flags is exposed in the river bed. This is the type section for the Llandeilo Flags Formation, which comprises units of thin limestones, flagstones and shales dipping southward at 60–70º. Since Murchison first described the geology of the Llandeilo area in the 1830s, these strata have yielded a rich fauna, including the trilobites *Basilicus tyrannus* and *Ogygiocarella debuchii*, and brachiopods *Sowerbeyella antiqua* and *Dalmanella parva*. The river section can best be accessed near Talhardd (SN622203), which is reached via a farm track from the A476. Here the Upper Llandeilo Flags are exposed in the river bed and in the riverside track.

8. Dryslwyn Castle (SN554204)

Take the A476 from Ffairfach, then follow the B4300 for *c*. 6km along the south side of the Tywi Valley. Turn right on to the B4297 to Dryslwyn Castle, which stands on the north bank of the river. There is a car park and picnic area near by. Walk up to the steep path to the castle ramparts in order to examine the limestone crags. The BGS 1:50,000 map (Sheet 230 Ammanford) shows this to be a faulted outlier of the Crug Limestone (the lateral equivalent to the Birdshill Limestone and the Sholeshook Limestone), which belongs to the Ashgill Series. This limestone consists of brown-yellow weathered calcareous flags that dip steeply north-west. These strata are faulted against the Llandeilo Flags Formation (Upper Llanvirn Series) on the south-east side of castle hill overlooking the Afon Tywi (Fig. 11, *overleaf*). Unfortunately these rocks are now unexposed due to dense woodland cover.

The Mydrim limestones and the overlying Mydrim shales form the northern flanks of castle hill. These were formerly referred to as the Upper *Dicranograptus* shales (Caradoc Series) and they

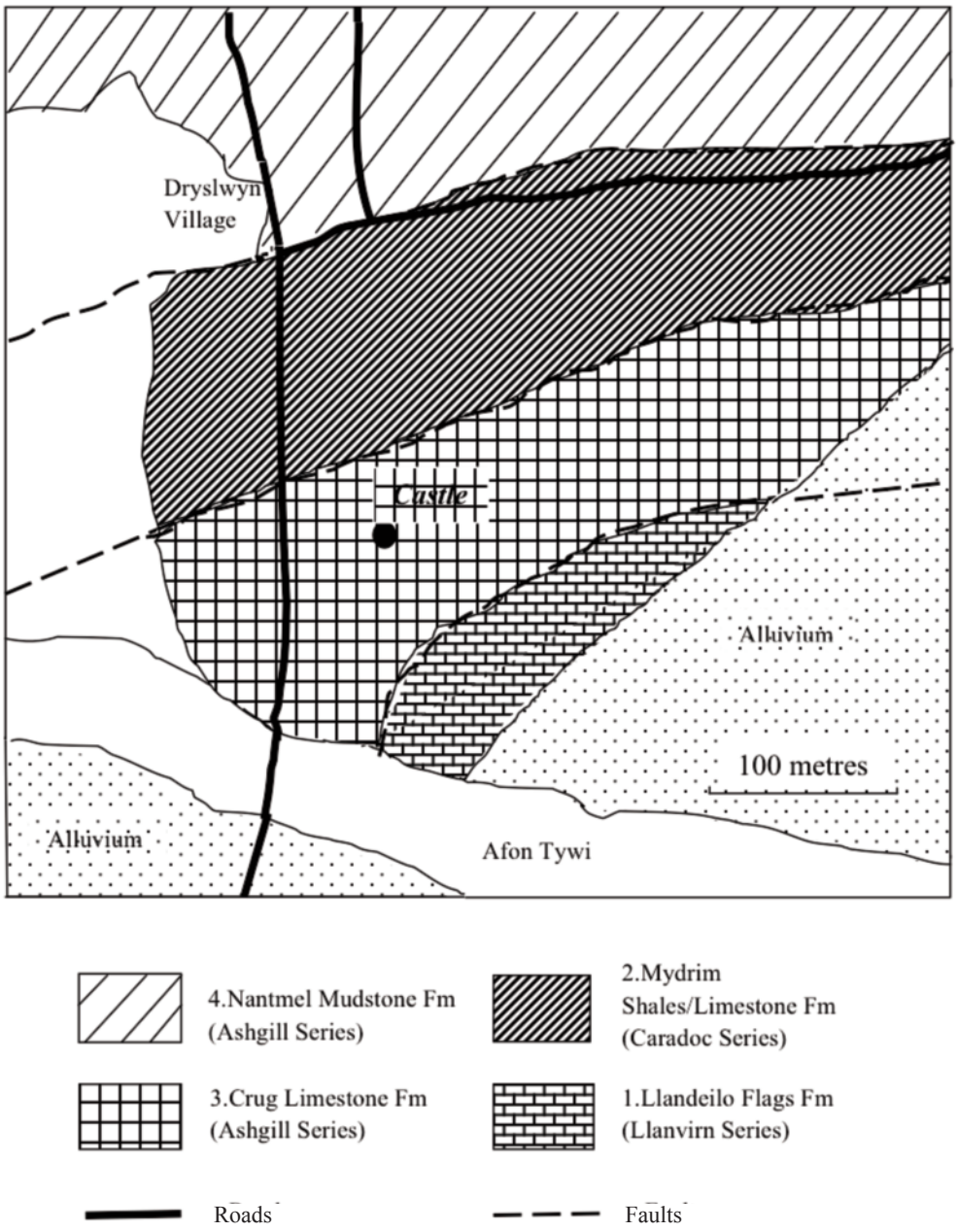


Figure 11 Geology of Dryslwyn Castle Hill (based on a map by H. H. Thomas [1907]).

are rich in graptolite remains deposited in a deep-water environment on the south-eastern margins of the Welsh Basin. By contrast, the shelly limestones were laid down in a shallow-water littoral environment. It is probable that uplift and subsidence along the Tywi lineament (a complex of faults and folds including the Tywi anticline) was a controlling influence on the position of the shoreline during Ordovician times.

After exploring the castle ruins, you should take time to overview the Tywi Valley, particularly westward toward Carmarthen. This view provides an excellent example of a mature river meandering over a wide alluvial flood plain (Fig. 12, *opposite*). There is a superb point bar on the south bank of the river, where sand and pebbles have been deposited as the current slows around the inside of the bend (Fig. 13, *opposite*). About 1km east of the castle you should be able to recognise a cut-off meander or oxbow lake produced by breaching the meander neck when the river is in spate (Fig. 14, *opposite*). In this area the Afon Tywi has a high index of sinuosity (channel length/straight line distance); in other words, it has developed exaggerated meanders as it flows slowly across its wide flood plain. The latter provides excellent damp pastureland for cattle, but since it often floods in winter, it is unsuitable for settlement.

9. Cwm Ffinnant (SN509201) and Cwm yr Abbey (SN500198)

Return to the B4300, turn right and drive via the village of Llanarthne to the picnic area and car park at Ffinnant (SN509201). Walk back along the road to Pont ar Ffinnant, where the stream can be accessed, although there is no designated footpath alongside the cwm. The strata exposed along the sides of the stream belong to the Afon Ffinnant Formation (formerly the lower Tetragraptus shales), which is mid-Arenig in age. In the stream immediately south of the bridge the rusty weathered shales yield trilobite remains including *Ogyginus hybridus*. For the next 250m the stream flows over a sequence of folded mudstones and turbidites, which form a series of cataracts. At the second footbridge a tributary stream joins the cwm, but you should continue to follow the main valley upstream past two waterfalls until you reach a flat marshy tract. Here there are black mudstones in the streambed, which contain a variety of trilobite fossils. A fault crosses the stream just north of Cwm-du Cottage and this marks the base of the Afon Ffinnart Formation, which rests on mudstones of the underlying Carmarthen Formation. The latter can be examined in the adjacent Cwm yr Abbey, which crosses the B4300 *c.* 1km west of Cwm Ffinnant. The strata in both stream sections dip consistently northward at 60–70º, and the beds strike across the stream channels. The Cwm yr Abbey Member, which forms the upper part of the Carmarthen Formation, is referred to as the *Peltura punctata* beds on the BGS map 1:50,000 Sheet 229 Carmarthen (1975). The characteristic olenid trilobite *Porterfieldia punctata* occurs within the mudstones of Cwm yr Abbey.

10. Morfa Ushaf (SN373124)

This marshland is located on the east bank of the tidal Afon Tywi *c*. 2km north of Ferryside. It is shown on the BGS 1:50,000 Carmarthen sheet as recent alluvium. It occupies a wide inside bend of the river, where mud and sand are being deposited from suspension as the tidal currents move up the creeks and inundate the marshland. The sinuous creeks extend out beyond the high-tide level across the salt marsh and mud flats as intertidal channels, which are exposed at low water. The marshland is colonised by reed beds, tussock grass and scrub woodland, and it provides

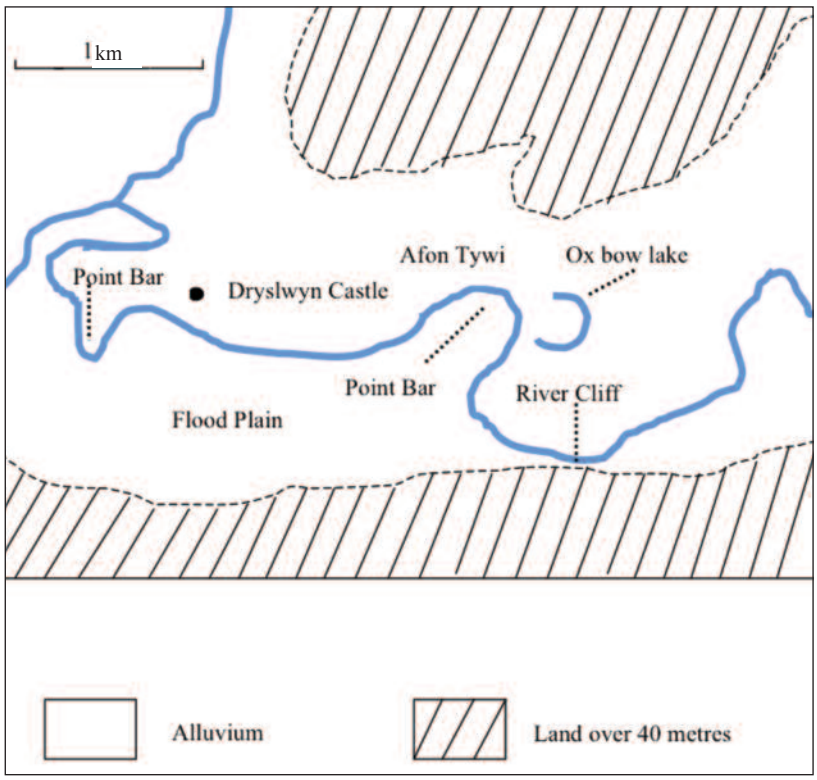


Figure 12 Afon Tywi flood plain near Dryslwyn Castle.

rough grazing for cattle and sheep. The area can be accessed by a footpath leading off the minor road from Ferryside, but an excellent overview can be obtained from the railway, which follows the Tywi from Carmarthen to the south of Ferryside, where the river enters Carmarthen Bay.

11. Llanstephan (SN355105)

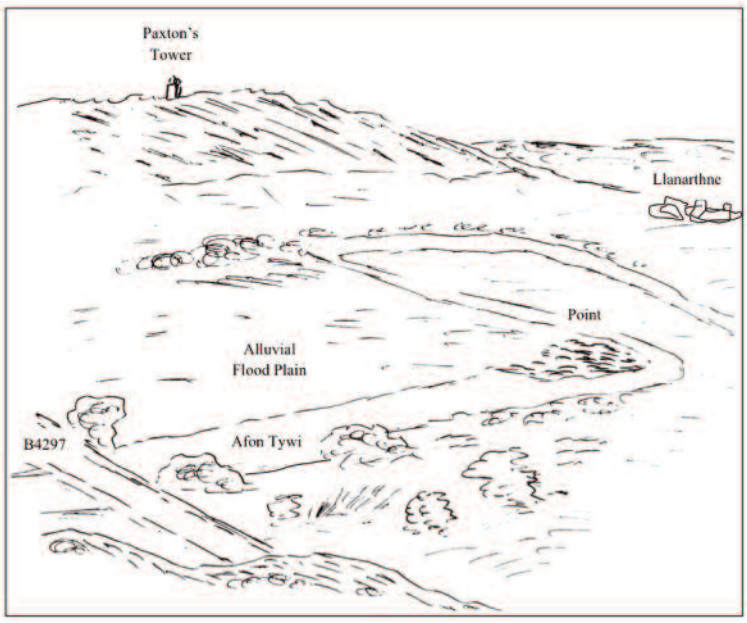
Llanstephan village stands on the west bank of the estuary of the Afon Tywi and it can be reached by the B4312 from Carmarthen (Fig. 15, *overleaf*). You should aim for the car park at the south-west end of The Green, which runs alongside the sandy beach. There are toilet facilities and a teashop near the car park. Llanstephan Castle stands on the headland overlooking the Afon Tywi. It was a Norman stronghold built in the 12th century and was briefly held by the Welsh folk hero Owain Glyndwr in the early 15th century, but was later retaken by the English. However, its strategic importance diminished and it fell into disrepair. Today its ruins form an impressive monument and tourist attraction.

Walk to the cliff section that extends from Llanstephan Castle for some 350m south-west to St Anthony's Cottage (SN347009). Here the strata are dipping north-west at 30–50° on the flank of the asymmetrical Wharley Point anticline. The Chapel Point Calcretes are exposed along the axis of the fold, which runs parallel to the cliffs below the castle (Fig. 16, *overleaf*). The succession is *c*. 15m thick comprising six calcrete profiles (Fig. 17, *overleaf*). The calcretes become increasingly mature toward the top of the sequence. They show increasing carbonate content upward and a gradation from discrete nodules, which increase in size and coalesce to form rubbly limestones at the top. The internal structure of each profile shows a fabric mostly perpendicular to the bedding and often forming pseudoanticlines. Calcretes represent fossil soils produced in a tropical climate of alternating dry and rainy seasons. In the wet seasons, ground water percolated down through the mudstone and picked up calcium carbonate and other minerals. In the dry seasons, the waters were drawn up by evaporation and deposited much of their mineral load, commonly replacing or filling rootlets or making irregular nodular masses within the soil. The Chapel Point Calcretes correlate with the Psammosteus Limestone and the Bishop's Frome Limestone, which are developed across South Wales and the Welsh Borders. They represent a prolonged period of stability when the alluvial floodplains were drying out under arid conditions leading to the formation of carbonate soil profiles.

The calcrete beds are overlain by conglomerates, cross-stratified sandstones and red mudstones of the Freshwater West Formation, which were formed during a major period of fluvial sedimentation dominated by meandering rivers that traversed wide flood plains and deltas. These beds form the cliffs that extend south of St Anthony's Cottage. The axis of the Wharley

Figure 13 Meanders on the Afon Tywi near Dryslwyn Castle (photograph by John Downes).

Figure 14 View of Tywi meanders looking south-west from Dryslwyn Castle.



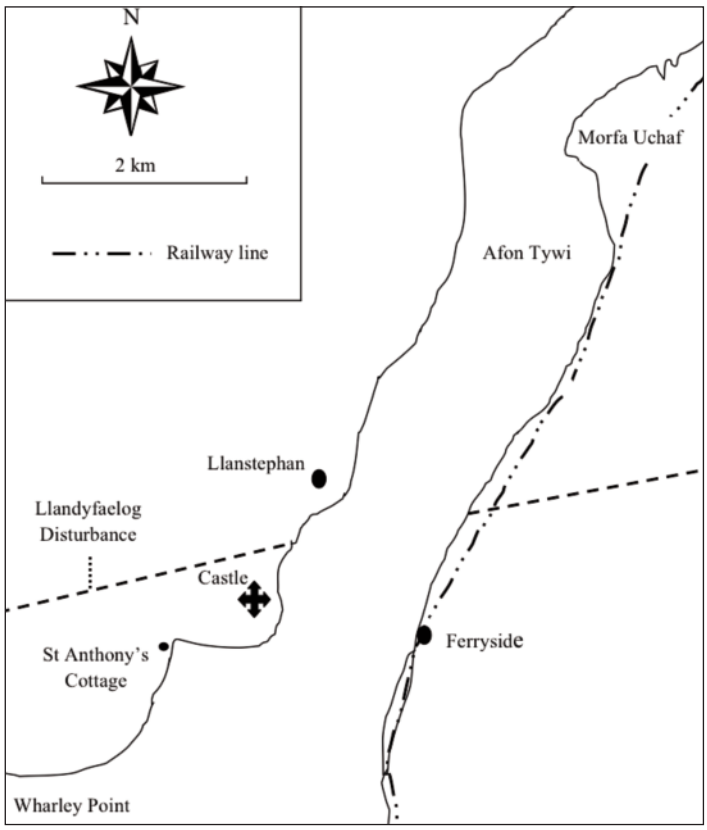


Figure 15 The Afon Tywi estuary.

Point anticline cuts the cliff line *c*. 250m south of the cottage and beyond this point the beds dip gently south. Conglomerates occur in the lower part of the succession and overlie erosion surfaces suggesting braided shallow rivers that alternately flooded then dried out for long periods. There are several fine-grained sandstones that exhibit lateral accretion surfaces, which are inclined at a steeper angle than the dip of the main bedding planes (Fig. 18). Lateral accretion takes place on the inside of a meander bend where sediment accumulates on the point bar. Here the river channel runs perpendicular to the cliff face, as the sediment would build out in successive layers to form a point bar. Large infilled burrows of the trace fossil *Beaconites* occur as dark circular patches on some bedding planes.

There are several good examples of small thrust faults in the cliffs near St Anthony's Cottage, and some bedding planes show

Figure 16 Chapel Point Calcretes in Llanstephan Cliffs.

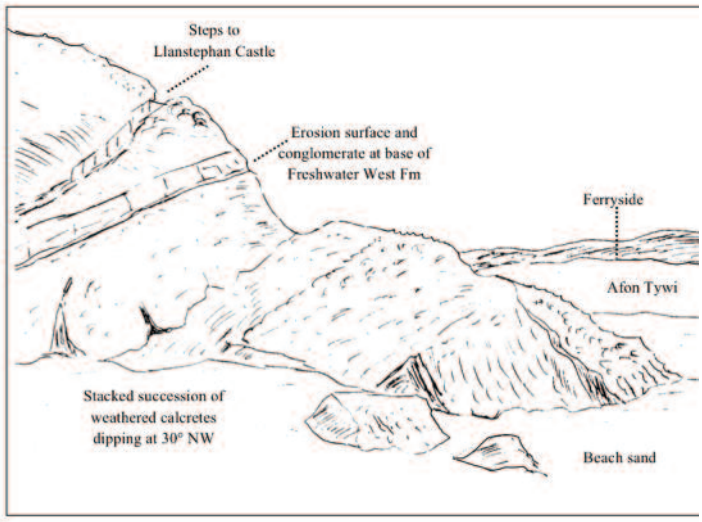


Figure 17 Chapel Point Calcrete beds in Llanstephan Cliffs (photograph by John Downes).

rectilinear jointing. Well-developed, south-dipping cleavage can be seen in some of the red mudstones. These tectonic structures are related to the Variscan Orogeny, which was also responsible for the Llandyfaelog Disturbance. This major fault runs along the northern side of Llanstephan Castle and reaches the coast near the village, and it is almost parallel to the axis of the Wharley Point anticline.

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Figure 18 Lateral accretion surfaces near St Anthony's Cottage, Llanstephan (photograph by John Downes).

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Ordnance Survey 1:50,000 Sheet 146 Lampeter & Llandovery
Geological Survey 1:50,000 Sheet 229 Carmarthen
Geological Survey 1:50,000 Sheet 212 Llandovery

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Book review

Misra, Kula C. 2012 *Introduction to Geochemistry: Principles and Applications*. Oxford: Wiley-Blackwell (ISBN 978-1-40512-142-2; paperback, 452pp; £37.50)

Prof. Misra has taught geochemistry, economic geology and environmental geology at the University of Tennessee for over 30 years, after working as a field geologist for 10 years. This book attempts to impart to the reader a wide knowledge of 'introductory' geochemistry, both in space — from atomic-scale structures that determine the chemical properties of elements to global-scale biogeochemical cycles — and in time — covering nucleosynthetic processes from the Big Bang to supernovae and radioisotope systems. A grounding in 'elementary' (possibly what I would have called A-level) chemistry, mathematics and earth science is assumed.

The book starts gently with an 'Introduction' and two chapters on 'Atomic Structure' and on 'Chemical Bonding' that I think OU earth science students should be familiar with. Then the real fun begins with chapters covering 'Basic Thermodynamic Concepts' and the 'Thermodynamics of Solutions', leading on to applications of these in 'Geothermometry and Geobarometry'. OU students will be hopefully familiar with some of the basics behind these applications, but this book goes much further to explore the quantitative nitty-gritty whys and wherefores of P-T reaction slopes and curves. A chapter on 'Reactions Involving Aqueous Solutions' concludes with a detailed (again quantitative) section on the chemical weathering of silicate minerals. Acid mine drainage caused by the oxidation of sulphide minerals and microbially mediated processes useful in the recovery of metals from low-grade ores are just two of the topics covered in 'Oxidation-Reduction Reactions'. If thermodynamics determines whether reactions can take place or not, 'Kinetics of Chemical Reactions' shows just how fast (or slow) these reactions may proceed. Some applications of 'Radiogenic Isotopes' (i.e. isotopes produced by radioactive decay) discussed in the book are radiometric dating of minerals, rocks and other materials; as tracers of geochemical processes such as magmatic differentiation and crustal evolution; tracing transport paths and sources of dissolved and detrital components of mineral deposits and rocks. 'Stable Isotopes' discusses uses beyond those familiar from S369, including tracing crustal contaminants of magma and mixing of hydrothermal fluids with some novel applications in oceanic palaeochemistry and tracing contaminants of groundwater. 'The Core-Mantle-Crust System' starts (naturally) with the Big Bang and traces the evolution of the Earth through the early Solar System, crust/mantle differentiation, generation of magmas from Archaean komatiite to modern MORBs and the generation of Earth's hydrosphere and atmosphere. 'The Crust-Hydrosphere-Atmosphere System' is a review of the current composition of these components of the Earth Supersystem and how different models may be used to show how they may have evolved over geological time.

Chapters follow a consistent format: an introductory section before the main 'meat' of each chapter, and a summary at the end; then a section with a recapitulation of terms, concepts and computational techniques introduced therein and a final section containing a set of questions with which readers are invited to test their understanding of the chapter.

The author has taken care to derive, where reasonably possible, all mathematical relations and chemical concepts from first principles so that the reader is not just presented with a series of 'rabbit-out-of-hat' statements to be taken as gospel, an approach that I strongly approve of. Most of these are in special text boxes so as not to unduly disrupt the general flow of the text. Each chapter also contains a number of worked examples that demonstrate the use of the relevant geochemical principle in real-life environmental and geological problems and in a quantitative manner. It is useful to reinforce one's learning by following these through and not just skipping over them. By doing so, you might find, as I did, that a number of the penultimate steps in calculations have wrong signs or transposed digits, but where the preceding steps and the ultimate results are self-consistent and correct: my thoughts were that an early reviewer of the manuscript had commented 'show more working' (as my teachers used to say) and that some of these steps had been inserted in haste late in the publishing process. A few 'spooling mistukes' were also evident.

One of the 10 appendices is a set of answers to selected chapter-end questions. Unfortunately I couldn't find any resource that gave the fuller set of answers or workings (unlike, say, Atkins' *Solutions Manual to 'Elements of Physical Chemistry'*), so the reader may feel left somewhat in the dark! The other appendices provide more supplementary materials, including various elemental and ionic properties and a standard-state thermodynamic data table that is useful for calculating answers to questions if you want to get results consistent with those stated.

The book is rounded out with a large (24 pages) and comprehensive set of references.

All figures and tables from the book are available for downloading (in PowerPoint and PDF respectively) from the Student Companion Site: www.wiley.com/go/misra/geochemistry.

This is a good book to study if you want to build your understanding of geochemistry on a solid quantitative footing.

— *Stuart Swales, BA (Cantab) Natural Sciences* (Physics)

Igneous rock names: a rough guide

Terry Cox

A passing reference made to igneous rock terminology in a recent OUGSJ paper — in an article describing a trip to China [*OUGSJ* **33** (2) 2012, 55–62 — Ed.], drew my attention, this being a topic of great interest to me. For some time I have been (intermittently) investigating the petrology and provenance of Neolithic group IV axes. Their petrological description has evolved since the original 1941 grouping (Keiller *et al.* 1941; Stone and Wallis 1951; Evens *et al.* 1962; Clough and Cummins 1979), but none of the names used to describe the rock in that and later papers adequately matches what I would use to describe the outcrop of their purported source — Balstone, near Callington, Cornwall — today.

These axes have been variously described as consisting of 'Greenstone', 'Sheared Tremolite Rock', 'Picrite', 'Altered Picrite', 'Altered Peridotite' and 'Peridotite'. It has sometimes been difficult to tell from the literature if the axes truly belong in the same group and therefore what relationship they have with the (head firmly on block!), meta-olivine orthopyroxenite at Balstone. Indeed, many of the axes *have* been transferred into other groups over the past 70 years.

There has been a concerted international attempt to construct a classification system for igneous rocks over the past few decades, under the auspices of an International Union of Geological Sciences (IUGS) subcommission, which advocates consensus with regard to igneous rock names and their definitions. A standing convention is charged with hammering out the details and reporting on the results.

To that end the IUGS has published two editions of *Igneous Rocks: A Classification and Glossary of Terms* (Le Maitre (ed.) *et al*. 1989 and 2002), which, as the name suggests, is in two parts (mis-referenced in *OUGSJ* **33** (2) 2012, as 'Walter, R. 1989'— Ed. apology). The first part sets out the recommended frameworks for giving a rock a particular name, the second lists every igneous rock name ever published, indicating the legitimacy of current usage.

Albert Streckeisen, in the forward to the 1989 edition, alludes to 12 previous attempts at a classification system, the results often ending up as bizarre and obscure entries in the glossary. But the need for a classification system is indisputable, for all sciences require their nomenclature and information to be communicable and unambiguous. Problems addressed include ratifying or rejecting names applied over space and time for similar rock types, e.g. Dolerite, Diabase, Microgabbro (all still valid); performing the same function where the same name has been applied to rocks of varying mineralogy and/or chemistry. For example, when the international geological community was asked what its members considered to constitute Andesite, the replies included rocks otherwise deemed to be Basalt, Basaltic Andesite, Dacite, Trachyte or Trachyandesite. Much the same elasticity was applied to the parameters of Monzonite.

A major issue was the general lack of chemical or mineralogical constraint on rocks with a localised incidence and also those from older literature (e.g. Syenite — named from its original type locality near Aswan, Egypt — turned out to be Hornblende Granite).

Although special names for some local rocks were recognised, the use of our Luxulianite, Lundyite and Minverite as rock names is not recommended, and Trowlesworthite (red Orthoclase, Tourmaline, Fluorite with minor Quartz), outcropping close to Shaugh Lake Clay Pit on Dartmoor, is considered obsolete. Incidentally, the Norwegians must have a crack public relations team, as there are dozens of legitimised rock names from the Fen Complex near Telemark, although like all special local names these only apply to rocks from that location.

The classification works by first placing the rocks in one of 13 divisions, each containing those deemed to be related by fabric, texture, mineralogy or chemistry. Starting with Pyroclastics and on through Carbonatites, Melilite-bearing, Kalsilite-bearing etc., finishing with Plutonics, Ultramafics and finally Volcanics, the idea is that in order to identify a rock, one works through the divisions until the apposite one is reached, each division being headed by a narrow set of definitions enabling one to determine whether a rock is appropriate to it or not. Within each division are descriptions, diagrams and/or tables setting out the parameters for giving a rock a particular root name. Other chemical or mineralogical information that can be obtained from the rock can be added as a prefix, in order of increasing abundance (incidentally, the opposite to the convention adopted for metamorphic rocks), and the validity of applying any special names determined.

Most of the relevant rocks in south-west Britain will fall within the Plutonic, Volcanic or Ultramafic divisions and these have internal hierarchies of classification, much of which is hopefully familiar to the reader. Ultramafics are those with at least 90% mafic minerals (M >90%), these are the dark minerals such as Olivine, Pyroxene, Amphibole, Mica and also primary Carbonate minerals. They are named according to their ratios of Olivine/Pyroxene/Hornblende or Olivine/Orthopyroxene/Clinopyroxene, by volume %.

Plutonic rocks have a modal grain size >3mm, M <10% and are named according to their ratios of Quartz/Alkali Feldspar/Plagioclase Feldspar/Feldspathoids (QAPF), by volume %. Rocks that otherwise qualify as Plutonic because they are not obviously Volcanic, but have a grain size 1mm–2mm are prefixed with 'micro-'. This often applies to dykes and sills. Subdivisions within the Plutonics include a differentiation between Diorite and Gabbro based on calculating how calcic the Plagioclase is, although this does require the examination of a thin section of it. There is also a classification of Gabbros, plus a colour-based classification to determine 'Leuco-' and 'Mela-' varieties of Plutonic rock. A field classification is available for a rough idea of where on the QAPF diagram a specimen is likely to fall.

The latter classification is also used for Volcanics, but with a modal grain size of <1mm its use in this division is probably redundant. Again the QAPF diagram is used, although even with a thin-section it is likely to be ineffectual. Instead, the IUGS recommends the more technical Total Alkali-Silica (TAS) method of determining Volcanic rock names (Sabine *et al.* 1985). The elemental abundance of a specimen is calculated using, for example, mass spectrometry. These are then converted to theoretical oxides by combining the rock's major elements with all its available oxygen, in a prescribed order, until the oxygen is exhausted. By using the ratio of $Na_2O + K_2O$ to SiO_2 (by mass %), the rock name can then be determined from the TAS diagram. These and

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other oxides are also used in subclassifications to identify those rocks allowed special names, such as the high-Mg Picrite and high-K Shoshonite.

In a 1902 paper, W. Cross *et al.* published a calculation that used all of the oxide data to create a set list of possible minerals that could theoretically be present, again in a prescribed order (Cross *et al.* 1902). Now much extended, the relative abundance of these normative minerals is used to determine a technically accurate rock name. Purchase of Le Maitre (ed.) *et al.* 2002 gives access to a downloadable C++ program that assesses the oxide data electronically, using what is now called the CIPW norm calculation, named from the initials of Cross and his three co-authors.

Some earlier efforts to produce a comprehensive classification for igneous rocks have obviously influenced this latest one. A late 19th-century arrangement utilised Feldspar chemistry, SiO_2 and Alkali Oxides — similar to a combined QAPF and TAS system. Within the glossary to Le Maitre (2002), however, lurk clues to some less coherent attempts. In an era lacking absolute dating technology, grouping basalts by age might seem over-optimistic. In 1859 G. G. Winkler contended that the Bavarian Basalt was neither Palaeozoic Melaphyre nor younger Trapp, so, on a temporary basis invented the name Allgovite, cited in the OUGSME China trip report in *OUGSJ* **33** (2) (Winkler 1859). Although it is a system rather than classification, in the early 20th century D. S. Belyankin devised a mnemonic terminology using a rock's minerals, abbreviated, to produce its name, beginning modestly with Bineite (Biotite and Nepheline), Dimelite (Diopside and Melilite), but raising the bar ever higher (Belyankin 1929). Inspired by this, A. Johanssen gave us Topatourbiolilepiquorthite — worthy of a Welsh railway station and equally difficult to enunciate (Johanssen 1931). Thankfully this idea did not catch on.

The IUGS glossary entries can broadly be categorised as either recommended root names, obsolete names, or names whose use is no longer recommended and are considered petrologically unsound. It is sometimes hard to understand the rationale for recommending some terms and not others. The obsolete Runite proposed for Graphic Granite seems perfectly reasonable. Monomineralic rocks are another case in point. True, the nomenclature can be a little clunky, sounding like elocution exercises for aspiring ventriloquists, but they are generally self-evident and logical. So we are familiar with the recommended Anorthosite, but Microclinite is vetoed, as is Magnetitite, Amphibololite, Biotitite and its attractive proposed alternative, Glimmerite. However, Ultramafic Plutonic Melilitolite and its Volcanic equivalent Melilitite are acceptable.

Some of the etymology is interesting. Un-recommended Leckstone was used for lining the bottom of Scottish ovens, otherwise it is Teschenite, a special name allowed for Analcime Gabbro. Modern Phonolite is the Latinised (via Greek) version of German Klingstein, named for the ringing sound made by a hammer blow against it. My favourite has to be Charnockite, an Orthopyroxene Granite and one of a group of rocks forming the Charnockitic division. Its original type locality is the gravestone of one Job Charnock in Calcutta. Now *that* is immortality!

There should be no doubting of the need for the rigours of a modern classification system for igneous rocks, and most of the IUGS classification system is straightforward enough. I do have a few reservations though. I do not see why many local names become obsolete for the sake of uniformity while simultaneously producing examples such as Trondhjemite (Norway), Plagiogranite (Russia) and Leucocratic Tonalite (everywhere else), for the same rock; or why globally well-established names, succinct ones at that, have sometimes morphed into a style at which even Belyankin and Johanssen would have baulked. Wolgidite has become Diopside-Leucite-Richterite-Madupitic-Lamproite — and there are plenty more examples like this. Would it not be better to keep the old Lamproite names and use the mineralogy to define the respective rocks?

There are also questions regarding accessibility and practicality, especially for those of us who do not have a geological laboratory at our disposal. A thin-section costs *c*. £30, which is OK for the coarser-grained rocks (presuming one has access to a microscope), but for Volcanics an oxide analysis is probably essential, and such analyses cost much more than thin-sections do. I should also point out that the multiplicity of imperfectly overlapping naming methodologies used for Volcanics often produce a multiplicity of names, which kind of defeats the object.

The IUGS accepts that this is a work-in-progress, so it is only to be expected that a few anomalies still exist, resulting in the classification descriptions, tables and diagrams to occasionally conflict with the glossary. This appears to be the case with Ultramafics prefixed 'Olivine-'; Granogabbro, whose plagioclase is calcium-rich (An_{50}–An_{100}), is a term that has become obsolete, with no replacement, while the mineralogically similar Granodiorite is limited to more sodic An_0–An_{50}.

All things considered, particularly the complexity of this topic, the classification is quite successful and extremely useful, containing far more information than I can impart here. If, like me, you are not only interested in igneous petrology but thrilled by lists, tables and diagrams, then I can heartily recommend Le Maitre (ed.) *et al.* (2002), although hopefully others will not be deterred from taking an interest in the concept of classifying and naming igneous rocks.

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Author note

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Table 1: Igneous rock classes and definitions

Classification Group	*Approximate Definition*
1. Pyroclastics and tephra	1. Product of explosive volcanic events, classed by fragment size and texture.
2. Carbonatites	2. Plutonic or volcanic rocks containing >50% carbonate minerals by volume.
3. Melilite-bearing rocks	3. Plutonic or volcanic rocks containing >10% melilite by volume, with its proportion being greater than any feldspathoid present.
4. Kalsilite-bearing rocks	4. Plutonic or volcanic rocks containing the feldspathoid mineral kalsilite, though subject to qualification.
5. Kimberlites	5. Polygenetic, polymodal, CO_2-rich, potassic, ultramafic, intrusive rocks with a distinctive geological context.
6. Orangeites	6. Polymodal, H_2O-rich, ultra-potassic, peralkaline, intrusive rocks. Definition as yet poorly constrained. Unique to the Orange Free State.
7. Lamproites	7. Shallow intrusives or with limited extrusion. Ultra-potassic and per-alkaline. Defined by fairly precise chemistry of certain primary minerals and the complete absence of others.
8. Leucite-bearing rocks	8. Volcanic rocks that, after their elimination from the kalsilite-bearing rocks and lamproites, are named using their ratios of alkali feldspar, plagioclase and (the feldspathoid) leucite, with reference to the volcanic QAPF diagram.
9. Lamprophyres	9. Usually shallow intrusives, particularly dykes. Porphyritic, with M′ = 35–90 (the colour index used to describe proportions of dark, mafic minerals), essential biotite and amphibole, restriction of feldspars to the groundmass. Calcite and zeolites, when present, may appear as primary phases. Can be difficult to differentiate from other dyke rocks.
10. Charnockitic rocks	10. Enigmatic rocks described as 'igneous or igneous-looking', they contain essential orthopyroxene and are classified using their QAP ratios in conjunction with the plutonic QAPF diagram.
11. Plutonic rocks	11. Coarse-grained (>3mm), deep intrusives and their shallower, medium-grained (1mm-3mm) equivalents. Mafic mineral content (M) <90% by volume. Named using the plutonic QAPF diagram, all other minerals being ignored. There is also a sub-classification for gabbroic rocks.
12. Ultramafic rocks	12. Medium to coarse-grained intrusives and, unless catered for within other groups, fine-grained volcanics, with M >90%. Named using olivine-orthopyroxene-clinopyroxene or olivine-pyroxene-hornblende ratios, whichever is most appropriate.
13. Volcanic rocks	13. Fine-grained (<1mm) extrusive rocks or sometimes shallow rocks such as those found in dykes and vents, with M <90%. Named using the volcanic QAPF diagram or alternatively, TAS or CIPW.

Book review

Dyke, G. and Kaiser, G. (eds) 2011 *Living Dinosaurs: The Evolutionary History of Modern Birds*. London: John Wiley and Sons Ltd (ISBN 978-0-47065-666-2; hardback, 420 pages; £60)

It has been suspected for well over a century that birds are related to some dinosaurs. The idea drifted in and out of favour through the 20th century, but it has become the accepted wisdom in recent times. This book provides a 21st-century update on the knowledge as it stands. It consists of four parts and a total of 16 chapters, each written by acknowledged experts in the aspect discussed.

Part 1 covers the deep evolutionary history of modern birds. The class Aves appeared in the upper Jurassic, with *Archaeopteryx* as the most primitive branch and a sister-group to all later branches. The Jehol fauna of China were some 20Ma later and these fossils have advanced our knowledge considerably. Relationships in fossils are of course mainly decided by comparative anatomy and Chapter 1 gets right in there. I found it rather impenetrable, as would most people without an in-depth knowledge of dinosaur and avian anatomy. The useful glossary at the end of the book helped, but I think it could have been more comprehensive.

Part 2 discusses the contribution of palaeontology to ornithology. Modern ornithological taxonomy, using various types of molecular analysis, has fundamentally changed our understanding of the phylogeny of birds. No longer are anatomical and morphological criteria sufficient to determine relationships. So how does this affect fossil relationships, as no DNA or other biomolecular data remain? Molecular data are analysed to work out cladistic relationships and can give an indication of the antiquity of such relationships. However, there are major differences between the results from the two methods. Later in the book this is characterised as the 'Rocks vs Clocks' debate. Molecular methods base the modern avian tree (Neornithes) in the late Cretaceous whereas the fossil evidence puts it in the early Cretaceous. However, there is a suggestion that the gap is narrowing, using a 'relaxed clock' model instead of the previous 'constant rate of molecular evolution'.

Part 3 covers the evolution of key avian attributes, the main one of course being the use of flapping flight. Did it develop as a 'ground-up' takeoff or as a 'tree-down' glide with flapping? Studies of aerodynamics are at best inconclusive, but using juvenile modern birds as an analogue, 'wing-assisted incline running' (flapping under-developed wings to help run uphill, for example to escape predators) provides a clue to how flapping flight may have begun. The evolution of the avian genome is briefly discussed but, as too few species have had their genome fully sequenced, it is categorised as 'too early to say'.

Part 4 is entitled 'The Future – Conservation and Climate Change'. Some species/genera/families appear evolutionarily predisposed to extinction, for example those with low fecundity. Many birds are not able to move or adapt rapidly enough to global change. Thus we are left with the depressing final sentence that "… avian diversity is, in common with the rest of the world's biota, facing a bleak and uncertain future".

This book is a very useful synopsis of current understanding of avian evolution. However, it is at times heavy going and, as such, of limited use to most OUGS members. There is fascinating information in it, but it just takes some finding!

— Paul W. Speak BSc (Hons) Open, continuing Earth Science MSc student and keen birder

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Book review

Trewin, Nigel H. 2013 *Scottish Fossils*. Edinburgh: Dunedin Academic Press Ltd (ISBN 978-1-780460-019-2; hardback, 118pp; £30)

Being a soft-rock southerner, Scotland is not a place that I would normally associate with fossils and so this book caught my eye by its very title. It does what it says and highlights famous fossils, famous fossil sites and also details examples of more widespread fossils.

This is another very good publication from a well-known geologist and researcher of the flora and fauna of the Rhynie Chert and the Caithness fossil fish.

It provides a pictorial study of some of the most scientifically important and interesting Scottish fossils, such as the Charophyte algae in the unique Rhynie chert and the Palaeozoic scorpion growth-series found in East Kirkton limestone. There is also a large section on the famous Scottish Devonian fish, which have played such a large part in the study of fish evolution.

The fossils are arranged according to their biological classification from algae to mammals, with a final section dedicated to the fascinating trace fossils of Skye and Sutherland.

Each of the more than 100 fossils has a dedicated page, which includes interesting text, excellent photographs and relevant life diagrams. There is information on where to find each fossil and a little about their life history, relevant biological information and stratigraphic details.

The pages are attractively presented and the text has an easy to read style, which makes it the kind of book to dip into in odd moments.

There is much to learn on every page, and I particularly found the small section on Jurassic fossils worthy of note, as they are so laterally distant from the majority of UK fossils of that period. Any that I have found on Skye have been particularly distressed and very unlike those depicted in this book!

Will it make you want to get your boots on and head into the field for fossils? Of course it will, if fossils fascinate you — and even if they do not, I would still recommend this book for the scientific historical content alone.

This is a book that should encourage you to visit many of the fossiliferous sites in Scotland and to increase your awareness of the diversity that can be found there, if not the quantity.

— Yvonne Lewis-Cutt BA Hons (Open)

Imaging active lava flows

Michael James (Lancaster Environment Centre, Lancaster University)

Introduction

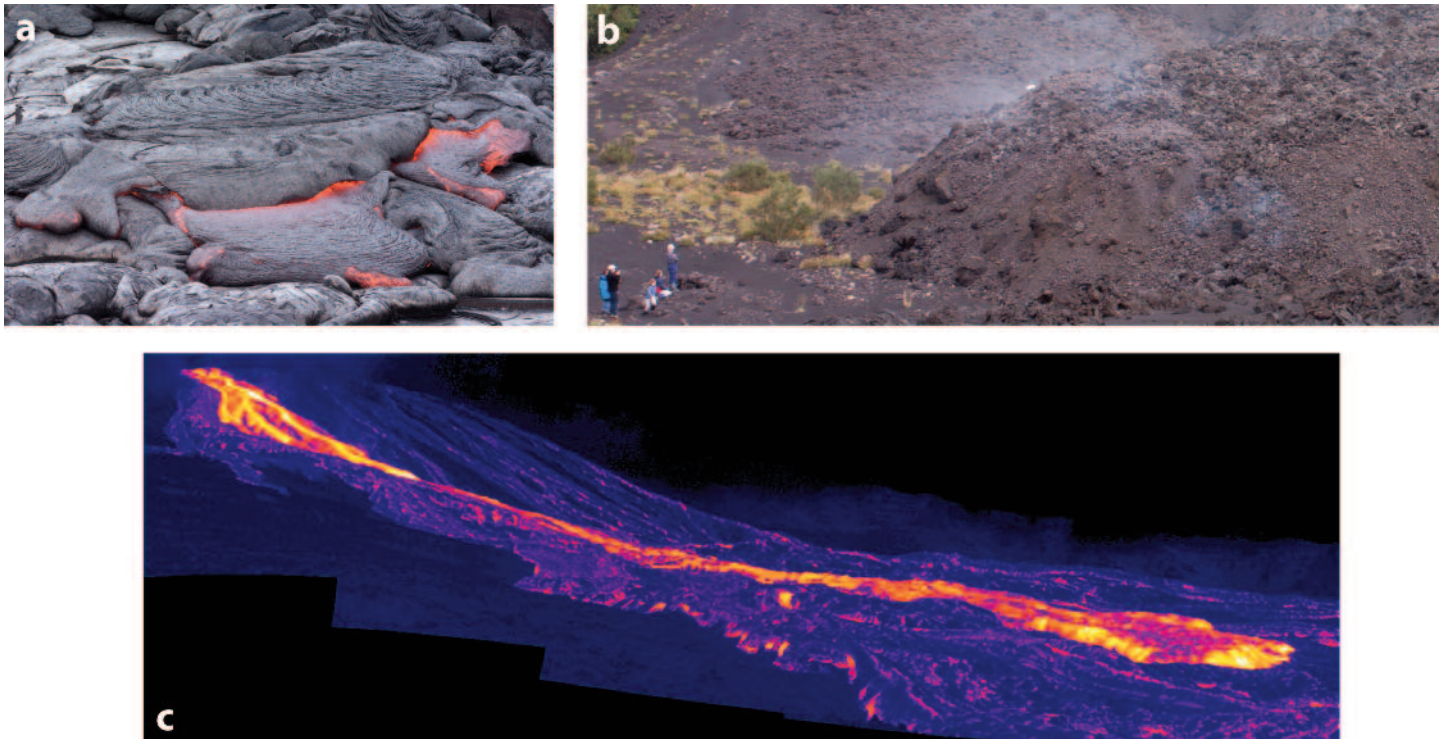
Unlike explosive eruptions, lava flows do not generally pose hazards over thousands of kilometres, but generally restrict their direct influence over distances up to a few tens of kilometres from a volcano. Nevertheless, lava flows have the capability to destroy valuable infrastructure and do occasionally cause fatalities. At volcanoes such as Mt Etna, Sicily, where effusive eruptions are relatively frequent and can present real threats to communities, understanding the emplacement of lavas is important for hazard assessment and civil planning. In Sicily, lava flow models are used extensively for this, but they rely on parameterisations that are often relatively poorly constrained. A recent focus of our research at Lancaster University has been to develop the use of modern imaging techniques to provide field data for validating and improving flow models. In this article, I illustrate some of the work that has been carried out using detailed time-series measurements and 3D data from active flows.

Lava and lava flow characteristics

Our early understanding of lava flows was driven by limited observations made during eruptions and geological interpretations of old flows. These observations have been built on and augmented by laboratory experiments, theoretical analyses and numerical computer simulations. Depending on the degree to which lava acts as a ductile fluid or as a brittle solid, different morphological styles of flow can be emplaced. If flows deform sufficiently slowly that motion can be accommodated by ductile processes, then smooth pahoehoe-like morphologies are formed (Fig. 1a). If flow (or deformation) is sufficiently rapid that flow surfaces begin to break up by brittle fracture, then 'a'ā flows are produced (Fig. 1b), where the fluid-like core of the flow is covered by a surface clinker. Typically, 'a'ā forms from more viscous lava than pahoehoe does, so advancing 'a'ā flow fronts are usually significantly thicker than initial pahoehoe lobes. 'A'ā flow fronts are also typically fed from levee-bounded channels that form behind the fronts as they advance (Fig. 1c).

Numerically modelling a combination of brittle and ductile processes is notoriously difficult, and would be impractical in most lava flow models. Thus, flow models are restricted to simulating the fluid-like behaviour, which, nevertheless, remains challenging. Lavas are dominantly poly-phase fluids (Fig. 2, *overleaf*), with liquid melt, solid crystals and gas bubbles (vesicles). Variations in the relative proportions of these components can change the lava from flowing like a simple fluid with a Newtonian rheology (such as water and Golden Syrup) to one with a complex non-Newtonian rheology. One of the most important non-Newtonian characteristics is the ability of a fluid to resist flow (like a solid), until a threshold force (or stress) is applied. Such fluids, for example, ketchup and toothpaste, are said to possess a 'yield strength'. During the flow of lava, cooling and degassing drive crystal nucleation and growth, bubble growth and coalescence, and the liquid melt itself can change its viscosity with decreasing temperature and degassing of dissolved water. As the crystal population increases, mechanical

Figure 1 (a) An active pahoehoe lobe on Kilauea (field of view is c. *1.5m across); (b) an advancing 'a'ā flow front on Mt Etna, with tourists for scale; (c) a composite thermal image showing an active channel-fed 'a'ā flow (here the image width represents* c. *800m. In (c), hotter areas are yellow/white and colder areas blue. The hot channel surface can be seen on the left of the image (with several small overflows spilling out from it), with other hot material exposed at the very front of the flow. The currently active flow is being emplaced on top of other recently active flows, as indicated by the dispersed warm patches across the image.*



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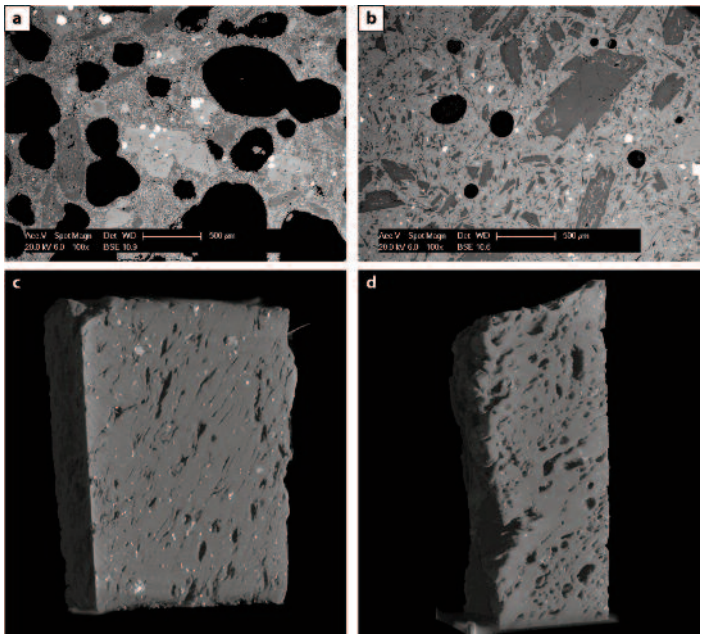


Figure 2 Backscattered scanning electron microscope (SEM) images of (a) a bomb from early in the 2008–9 eruption of Mt Etna and (b) a snow-quenched sample from a metre-wide flow (active toward the end of the eruption) that illustrate the distribution of different phases in lavas. Crystals of plagioclase are dark grey; pyroxene and olivines are paler and sometimes not dissimilar to the light-grey of the glass, which represents the 'frozen' melt; vesicles are black and Fe-Ti oxides are white. (c and d) show more angular vesicles in X-ray micro-tomograph models of vesicular rhyolite lava samples. X-ray analysis provides images inside samples, and tomography uses multiple images to build up complete 3D volume reconstructions of entire samples, with resolutions here of a few tens of microns. Such reconstructions show the vesicles throughout the sample and enable 3D analysis of their shape, distribution and orientations. Clear vesicle alignments (c) and heterogeneous distributions (d) give insight into the flow and shear history of the lava before it solidified (images (a) and (b) courtesy of Jane Applegarth; images (c) and (d) courtesy of Ian Schipper; samples collected from Puyehue Cordón Caulle [2012] by Jon Castro).

interactions between the crystals lead to the development of a yield strength that can then prevent parts of the flow from deforming and moving. In this way, levees and channels can form, as well as lava tubes, and, eventually, flows stop advancing. Thus, understanding the development of yield strength in a magma is critical for interpreting fundamental features seen on lava flows and for accurately modelling maximum flow lengths. Although rheological characteristics can be defined at the sample-scale by laboratory experiments, scaling such results up to full flows gives uncertainties owing to the wide range (in space and time) of the strain rates and temperatures involved in the bulk flow.

Modelling lava flows

Over the years, there have been a number of models produced to simulate the path and advance of individual lava flows. Several models are one-dimensional — they define the lava's down-slope progress by the path of steepest descent and update the physical properties of the flow by estimating the changes due to heat loss and crystallisation. Such models are quick to run, and useful for rapid forecasting of flow directions and potential maximum run-out distances. However, without being able to describe the lateral spreading of a flow, their capabilities are limited in the case of long-lived eruptions when effusion continues after the flow front has cooled sufficiently to stop advancing.

More complex models can simulate lateral spread as well as the down-slope advance of lava over topography (Fig. 3), but their sophistication means they take longer to run than 1D models. In order for simulations to be sufficiently rapid for near-real time forecasting scenarios, they can include significant simplifications, such as neglecting vertical variability within the flows.

It has long been known that effusion rate is one of the critical parameters that affect the length of lava flows. Higher effusion rate flows cool less quickly with distance than those with lower effusion rates, and so they travel farther. Our recent research at Lancaster has been to try and help numerical modellers by deriving bulk rheological properties of active lavas in the field, by measuring volumetric flow rates and by documenting some of the complex flow processes that affect the lengths of flows during long-duration eruptions.

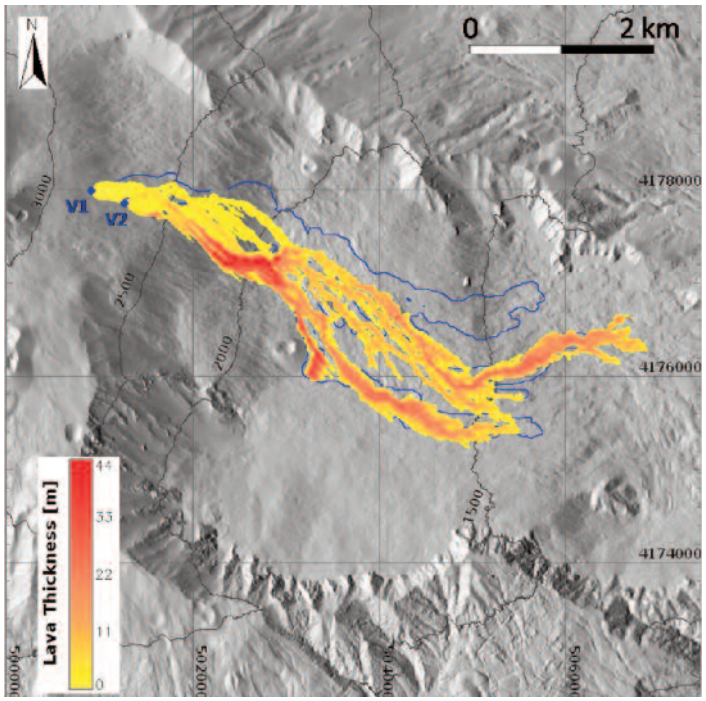


Figure 3 A simulation of the first two months of the 2008–9 eruption of Mt Etna, calculated by the MAGFLOW numerical computer model. The simulation results, coloured by the modelled flow thickness, are overlaid on a shaded image of Mt Etna's topography. The blue line shows the mapped outline of the real flow. Effusion occurred from two vents (V1 and V2), and the lavas flowedg east into the Valle del Bove. Using realistic estimates of the lava's temperaturs at eruption (1087°C) and solidification (827°C), the model successfully captures most of the main features of the flow field (simulation carried out by Gaetana Ganci and Annalisa Cappello of the Istituto Nazionale di Geofisica e Vulcanologia (INGV), Catania).

Volumetric flow rates

Most estimates of effusion rate are derived from thermal analysis of satellite data or from visual observations of lava flowing in channels. Satellite data can provide regular results that highlight the general effusion trend, but, due to the low resolution of the data (often multiple kilometres per pixel), uncertainties remain significant. In the case of visual observations,

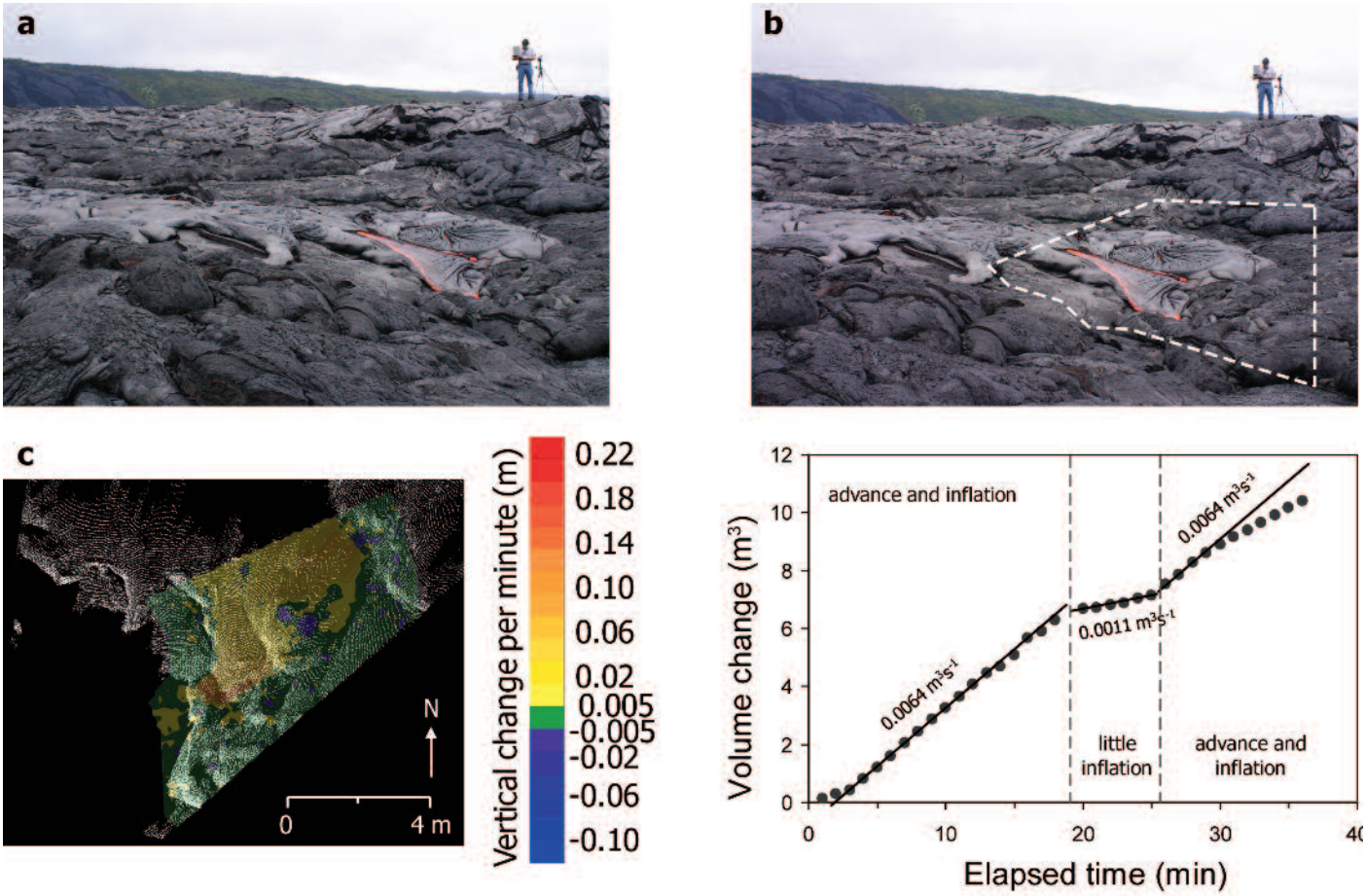


Figure 4 Stereo imaging of an active pahoehoe lava lobe, Kilauea. Simultaneous images were collected by tripod-mounted digital cameras mounted, giving left (a) and right (b) views of the advancing lobe. Photogrammetric analysis of each image pair made it possible to determine the evolving 3D position of the lava surface. In (c), the calculated surface points are shown in map-view, overlain by colour-coded vertical change since the previous image pair, a minute before. By comparing the evolution of the lava surface over time, the volume change can be calculated (d) highlighting the relationship between inflation of the flow and forward advance.

assumptions on the rheology and channel cross section need to be made in order to convert velocities into effusion rates. One other approach is to attempt to record the volume change of the flow through time. Post-eruption, this can be carried out by calculating the inundated area from maps and by estimating flow thickness, but during on-going events suitable maps are not always available.

Over smaller spatial scales, stereo time-lapse photography and photogrammetry can be used. Photogrammetry techniques enable 3D surface models to be determined from photographs taken from different positions. Figure 4 shows the results of this approach being explored on a pahoehoe flow lobe on Kilauea. Using two synchronised cameras enables the captured of a sequence of stereo-pairs that can be processed into a sequence of surface models of the advancing flow. Subtracting the first surface from the subsequent models then determines the volume change. Over the limited spatial scales shown in Figure 4 (10s of m), this can provide insight into how pahoehoe flows advance, but does not reflect the effusion rate at the vent because many such lobes may be active at any one time.

Developing the procedure to assess the advance of ‘a’ā flow fronts typically involves scaling up to flow thicknesses of *c*. 10m and widths up to 100m. However, in these cases, flow advance rates can be sufficiently slow that synchronised cameras are not necessarily required, and one camera can be moved manually to acquire multiple images while negligible flow movement occurs. Adopting this approach during the 2004 eruption at Mt Etna enabled us to construct repeated surface models of advancing flow fronts and to calculate volumetric advance rates (Fig. 5, *overleaf*). The results not only highlighted variability within the advance rates, but also showed that volumetric estimates made at the vent from velocity measurements may significantly overestimate volumetric advance rates at the front. The implication is that vent-based estimates may overestimate the effective volumetric flow rate that drives the front forwards — volume is being dissipated down-flow, and not all of this loss can be accounted for by degassing.

Particularly clear illustrations of flow variability and volume loss processes have been observed in channels feeding active flow fronts. Channel flow levels can vary between being bank full — where the surface of the lava flowing in the channel is at the same height as the surrounding levees — to being almost empty. These changes can be observed over timescales of hours and, in some cases, be represented by the flow of pulses, some of which can be sufficiently large to overspill the levees as they flow (Fig. 6). Thus, variability in flow rate can occur on temporal and spatial scales that are not possible to fully determine from satellite data, and their influence on the evolution of flow fields needs to be better understood. For example, a large pulse of lava could gently overtop levees (as in Fig. 6, *overleaf*), reinforcing them and strengthening the channel, or, alternatively, could potentially break levees to form a new active channel elsewhere.

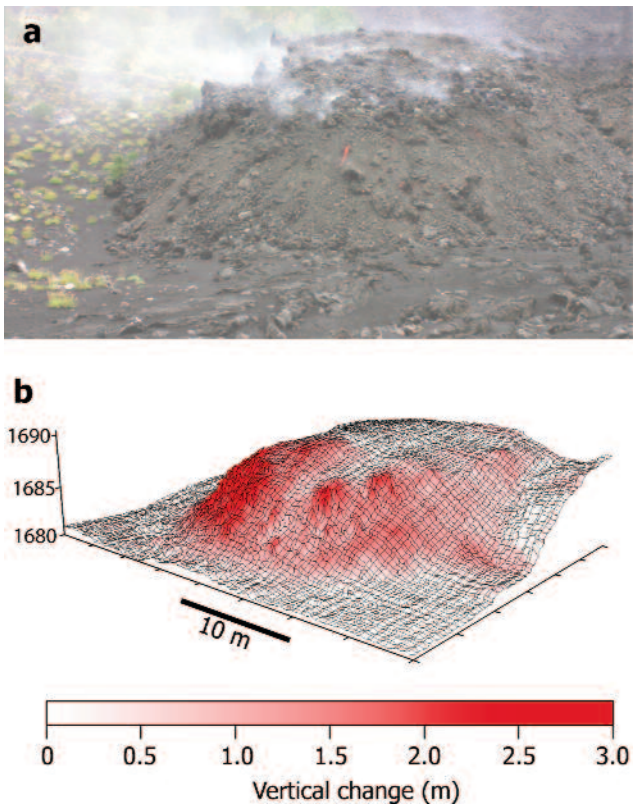


Figure 5 (a) An 'a'ā flow front, c. *5–7m high, advancing over flat ground towards the camera at Mt Etna, 2004; (b) a 3D wire-mesh surface model of the flow front derived using photogrammetric techniques. The shading indicates the amount of vertical change since the previous survey, which was made one hour before, and represents a volumetric advance rate of 0.22 m3s-1 (figures adapted from James* et al. *2007; for a time-lapse sequence illustrating the advance of this flow front, see youtu.be/18jPOrFEVS8).*

Flow rheology

Making rheological measurements of active lavas is usually very difficult. Direct measurements (using rheological equipment) are only possible in a limited set of circumstances, and generally cannot be carried out near flow fronts, owing to the hazards and to the strength of the material involved. Consequently, estimates are often made from surface velocity measurements made in channels. Assuming an idealised channel (e.g. one with semi-circular cross sections), rheological parameters can then be determined from formulae. If channel width, depth and slope are known, and the maximum surface velocity measured, then sufficient information is available to calculate an apparent Newtonian viscosity. However, if the lava is suspected to be non-Newtonian, then in order to estimate the yield strength, a second, independent set of measurements is required.

Unfortunately, lava channels generally do not have idealised geometric sections and, in particular, depth is usually extremely difficult to estimate or measure. However, during the 2004 eruption of Mt Etna, fortuitous conditions made it possible to determine surface velocities and depths from a combination of image-based methods (Fig. 7, *opposite*). During a period of near-complete drainage of the channel, photogrammetry enabled the estimation of channel depth. Then, under fuller flow conditions, surface velocities were determined from thermal time-lapse data. Because the channel region studied covered two different slopes, there was sufficient information to estimate non-Newtonian rheological parameters, such as the shear strength (*c*. 10kPa).

Although determining flow rheology in a channel is useful, it does not give insight into the rheological conditions that cause flows to stop advancing. Consequently, we are now trying to acquire sequences of high-resolution models of advancing 'a'ā

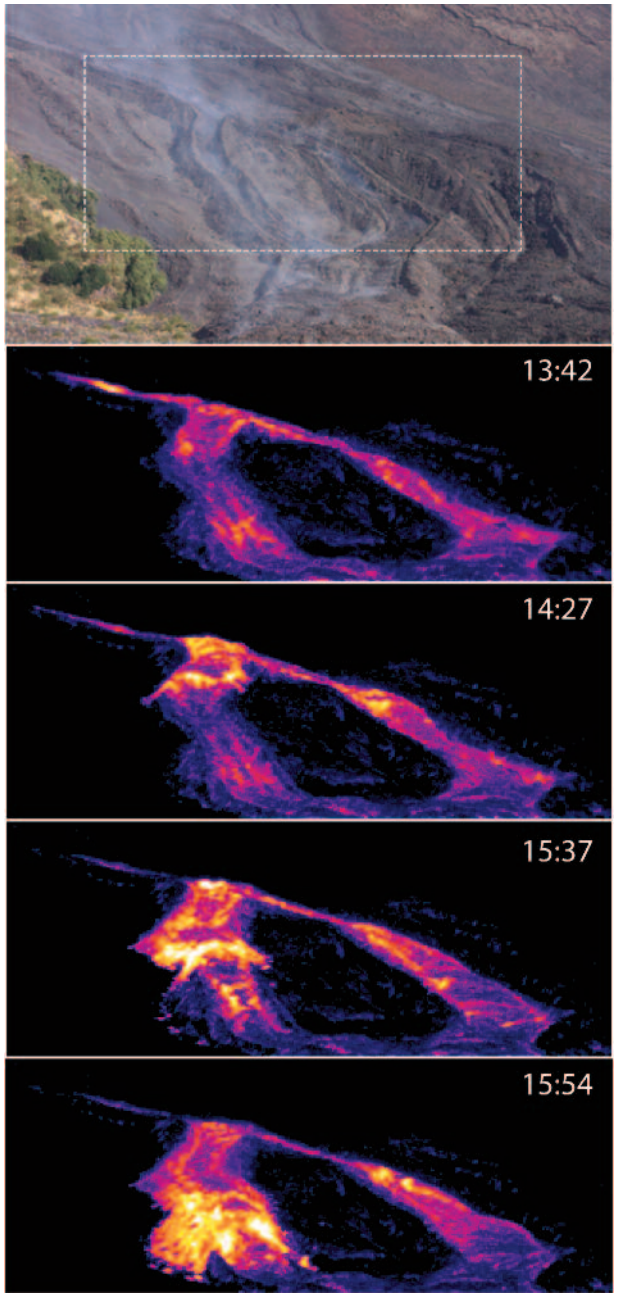


Figure 6 Short-term variations in channel flow rate, observed on September 27, 2004 at Mt Etna. (a) An active lava channel descending the headwall of the Valle del Bove bifurcates to feed flow fronts that advance over the flatter valley bottom. In the panels below, thermal images covering the area of the dashed box in (a) highlight the hot, active regions (orange and red); channels are c. *10–15m wide. A hot pulse of descending lava is initially seen in the upper channel (b) and rapidly reaches and splits at the channel bifurcation (c). In the lower channel (right), flow is maintained within the existing channel levees. However, in the upper channel (left), the levees are overflowed and, consequently, built up as the pulse passes (d, e). A time-lapse sequence of this event can be seen at youtu.be/s0chiMHspCI.*

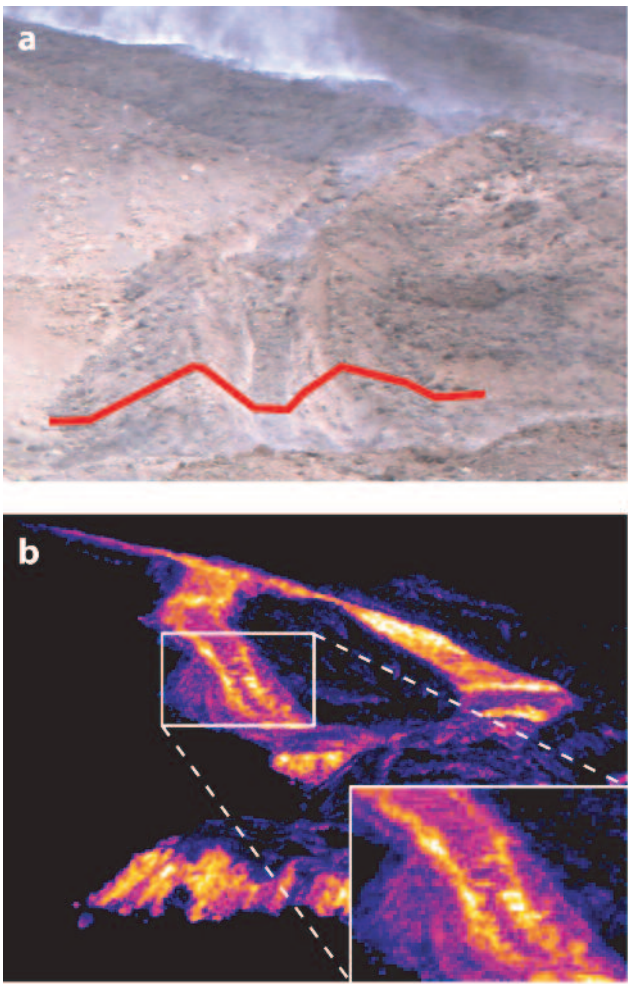


Figure 7 (a) A near-drained channel (Mt Etna, 2004), overlain with a cross section derived from photogrammetry. Note two pulses of lava (highlighted by their significant degassing) descending the channel at the top of the image. (b) (adapted from James et al. *2007) One of the thermal time-lapse images used to determine surface flow velocities (*c. *1.0–1.5m min-1) under fuller channel conditions. The enlarged section indicates the region shown drained in (a), for which a flow rate of* c. *0.1m3s-1 was calculated.*

flow fronts. Early work has proved promising (Fig. 8), but capturing a flow front as it comes to rest remains an elusive goal.

Complex flow processes

The work described above has involved data collected over relatively short periods of time (e.g. hours), so has not captured longer timescale processes that can also influence the development of flow fields and final flow lengths. When the eruption duration is longer than the time taken for an advancing flow front to cool sufficiently and stop, then the simple flow is transformed into a complex flow field. As the front stops moving, new material must be accommodated either by flow thickening (inflation), or by an up-flow levee failure or overflow, and a new flow being generated. Such processes have been captured by time-lapse imaging at Mt Etna (2009), showing flow inflation and levee overflows tracking up-flow towards the vent (Fig. 9, *overleaf*). In this case, even though advance was still occurring at the flow front, near the vent surface velocities decreased, the channel almost doubled in depth and multiple overflows were observed.

Over timescales of days to weeks, repeated flow cessation and new flow generation are common in low-effusion-rate eruptions. With low-effusion rates, flow fronts cannot advance far before

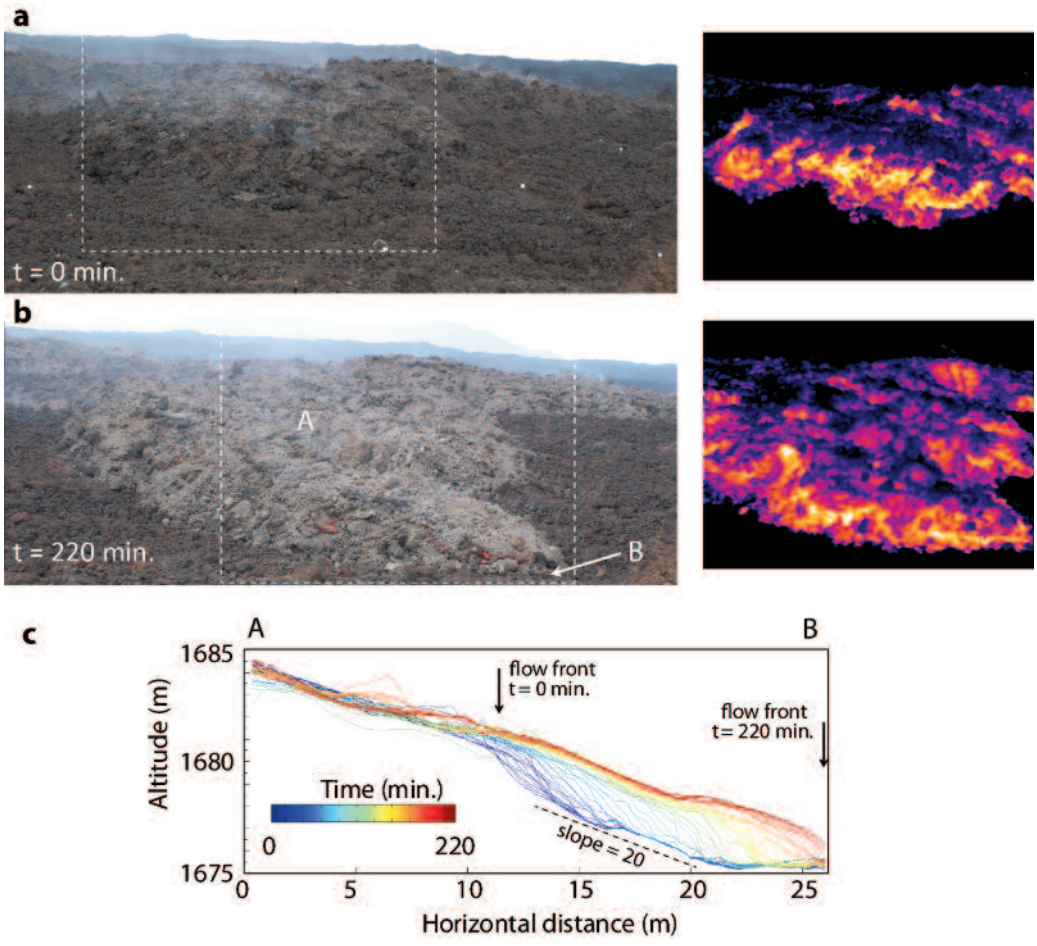


Figure 8 The advance of a very fluid 'a'ā flow front on Mt Etna, 2008. At the time, a broad flow front was advancing across the bottom of the Valle del Bove, c. *3km from the vent. Synchronised time-lapse cameras imaged one lobe of the flow front, only* c. *2m thick, for a period of* c. *3.5hr. The advance in seen in the differences between (a) and (b), where the panels to the right are thermal images covering the dashed boxes and helping to delineate the hot active flow. Photogrammetric analysis of the stereo sequences enables calculations of sections over the advancing lobe, so that changes in flow-front velocity and thickness can be determined. A time-lapse sequence excerpt from one camera can be viewed at youtu.be/F9VTl3jLlVE.*

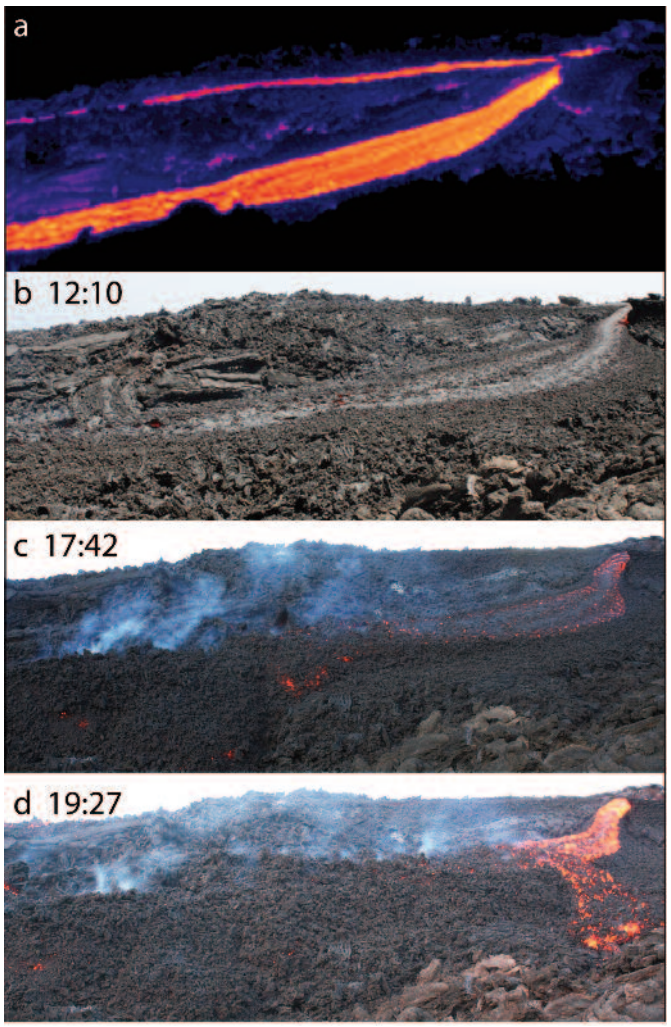
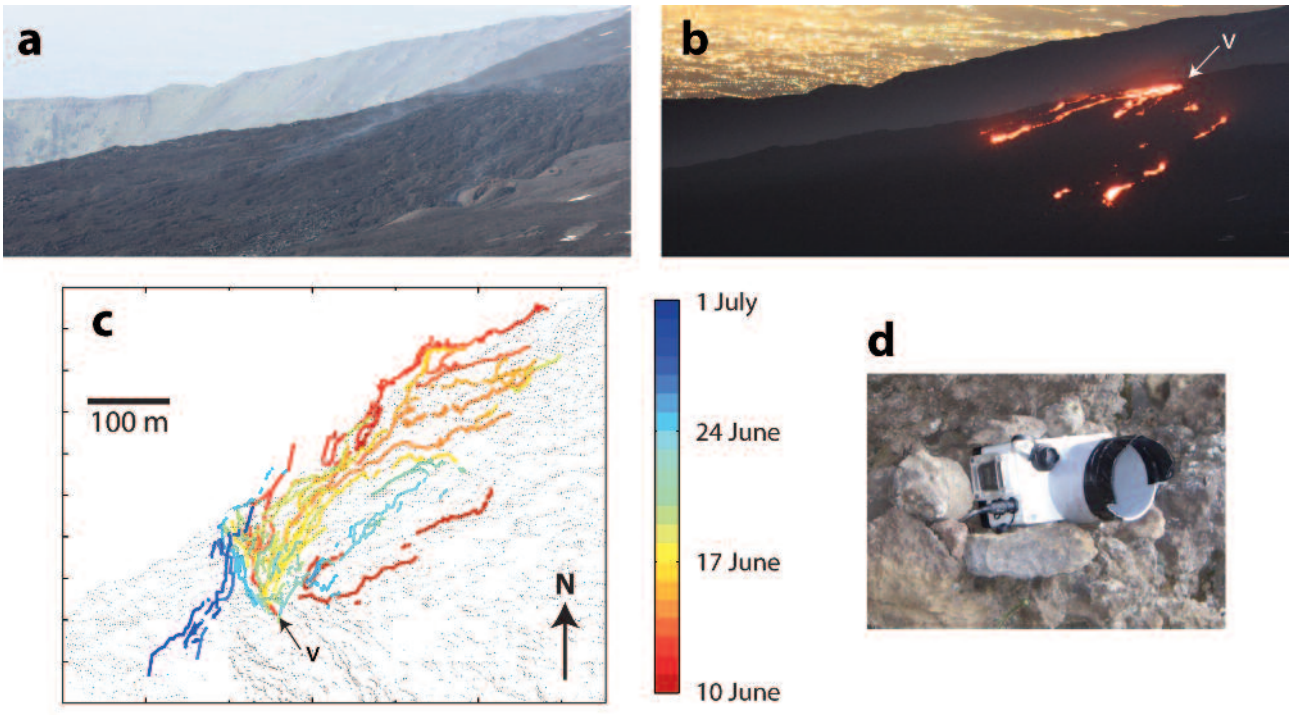


Figure 9 Flow inflation and levee overflows captured by a time-lapse camera at Mt Etna, June 10, 2009. At the time, gentle effusion was producing a number of small lava flows at the top of the Valle del Bove. In (a) a thermal image — taken from a position similar to the three-part time-lapse footage below — highlights in orange the two active channels that flowed from a small ephemeral bocca just off the right of the image (width of foreground channel varies between c. *1m and 5m). (b) At midday, the foreground channel had a smooth morphology with surface velocities (determined near the centre of the image) of* c. *80mm s-1. By* c. *17:45 (c), the channel had deepened significantly and now had a highly irregular surface morphology, with velocities dropping to* c. *30mm s-1, and being too small to detect (<10mm s-1) shortly after 18:00. The increased channel depth was supported by numerous small overflows that built the levees. One of the larger overflows (or a minor channel breach) is illustrated in (d). A full time-lapse sequence can be viewed at youtu.be/5nmWvGdhDco.*

they have cooled sufficiently to stop, necessitating the onset of inflation or breakout. Which of these processes occurs is important because if inflation is significant, the flow fronts can fail, resulting in a new lava flow formed from the originally stalled front. This process can then substantially lengthen a flow field through the eventual formation of insulating lava tubes. In contrast, if a channel breach occurs up-flow, then the new front will be expected to stop at a similar distance from the vent, representing flow-field widening, rather than lengthening.

Such repetitive behaviour was illustrated at Mt Etna during the end of the 2008–9 eruption (Fig. 10). As the effusion rate gradually declined, short lava flows repeatedly superimposed themselves to build up a substantial lava delta at the headwall of the Valle del Bove. However, multiple flows were active simultaneously, with the result that flow lengths remained substantially

Figure 10 Lava flows active towards the end of the 2008–9 eruption of Mt Etna were recorded by a remote camera installed high on the mountain. An excerpt (a) from a night-time image shows multiple short flows simultaneously active, and highlighted against the lights of Catania in the distance. By tracking the advancing position of flow-fronts through the image sequence and combining the results with a topographic model derived from a terrestrial lidar survey, flow tracks can be re-projected into map coordinates (b). As the eruption neared its conclusion, maximum flow lengths generally decreased, indicative of a reducing effusion rate. A sample of the time-lapse sequence can be viewed at youtu.be/VFHCFPn8Ggs.



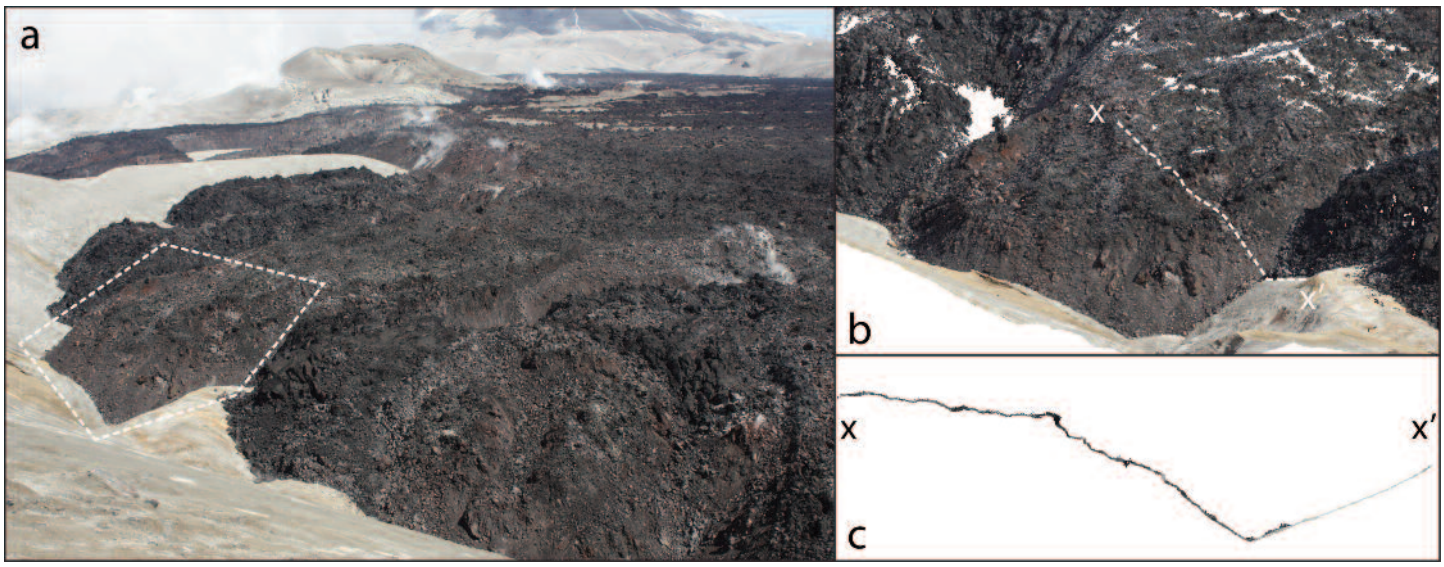


Figure 11 A 3D model of the recent rhyolite flow at Puyehue Caudón Caulle, Chile, derived from digital field photographs processed by computer vision software. (a) An example of the photographs used to create the model, showing the dark lava having flowed over a flat bottomed valley, up to the lighter ash-covered ridge from which the photo was taken. The lava was erupted from the cone in the near-background, with the partly shadowed main Puyehue edifice cropped off the top of the photo in the far background. (b) A view of part of the 3D model, covering the area indicated by the dashed line in (a). (c) is an example section (X–X') through the coloured model, with a flow thickness of c. *25m. A portion of the 3D model, approximately that seen in (b), can be interactively viewed and manipulated at: http://www.lancs.ac.uk/staff/jamesm/ptclouds/pcc_lava.htm.*

shorter than would be anticipated had the lava all flowed in a single channel at any one time. The factors that control how many flows are simultaneously active are, as yet, unclear, and are a target of ongoing research.

Future directions

This article has focussed on basaltic systems because their high level of activity provides frequent opportunities for data collection and, until last year, the emplacement of a substantial high-silica lava flow had not been studied. However, the recent (2011–12) eruption of Puyehue Caudón Caulle (PCC), Chile, produced a large rhyolitic lava flow field and enabled the first measurement of an active rhyolitic flow. Due to its remote location, transport of traditional surveying equipment to PCC would have been extremely difficult, so camera-derived techniques have been invaluable. Using modern computer software that can automatically generate 3D models from collections of photographs (Fig. 11), we are now able to make quantitative comparisons between the emplacement of flows with different rheological properties (rhyolite and basalt viscosities typically differ by factors of >106).

This, and most of the other work discussed in this article has been primarily driven by research goals and one of our key tasks now is to develop some of the techniques for monitoring purposes. An area of current focus is on combining the analysis of satellite data with results from ground-based cameras. Both space- and ground-based systems have advantages and limitations. For example, satellite data can be acquired at frequencies of up to four images an hour (e.g. SEVERI data), but only at low resolution (several kilometres per pixel), whereas ground-based time-lapse images can be acquired at high resolution and at multiple images per minute — but often from oblique views in which some areas are hidden within regions of rugged topography. Combining the analysis of both data streams could deliver a more flexible monitoring system that is also more resilient to technical failures and issues such as obscuration by cloud cover. The resulting estimates of effusion rate would help real-time lava flow models produce accurate forecasts for hazard managers and decision-makers during future events. A better understanding of flow processes will also help enable the use of flow models to guide mitigation measures such as flow diversion.

Acknowledgements

I would like to thank the OUGS for supporting the use of remote imaging by funding a time-lapse camera kit for understanding volcanic phenomena, through the Geoff Brown Memorial Fund. The camera is available for use by U.K. researchers, with details available on the web:
http://www.lancs.ac.uk/staff/jamesm/research/GBcamera.htm.

Most of the work described in this article has been inspired and facilitated by Harry Pinkerton, with his encyclopaedic knowledge of the nooks and crannies of Mt Etna. I gratefully acknowledge further fieldwork assistance from, or collaboration with, Matt Ball, Jane Applegarth, Neil Slatcher, Hugh Tuffen, Andy Harris, Jon Castro, Ian Schipper and many others. In Sicily, staff of Istituto Nazionale di Geofisica e Vulcanologia (INGV), in particular Sonia Calvari, have provided continued support, for which I am highly grateful. Jane, Ian and Gaetana Ganci are also thanked for kindly supplying images for the article. The research has been funded by the Royal Society and NERC (grants NE/F018010/1 and NE/I016414/1).

Reference

James, M. R., Pinkerton, H. and Robson, S. 2007 'Image-based measurement of flux variation in distal regions of active lava flows'. *Geochem Geophys Geosys* **8**, Q03005
[doi: 10.1029/2006GC001465]

Book review

Carracedo, Juan Carlos, and Troll ,Valentin R. (eds) 2013 *Teide Volcano: Geology and Eruptions of a Highly Differentiated Oceanic Stratovolcano*. Berlin, Heidelberg: Springer-Verlag (hardback ISBN 978-3-64225-892-3; £90 / eBook ISBN 978-3-64225-893-0; £72) (DOI 10.1007/978-3-642-25893-0; Library of Congress Control Number 2012953115)

Are you are one of the 300+ Open University Geological Society members who has been to Tenerife on one of our 'Volcanoes on a Shoestring' trips? Are you planning to visit the island, or perhaps you live there? Are you studying Earth sciences, particularly volcanology? If so you will want to have a copy of Carracedo and Troll's eagerly anticipated book.

Teide is the third tallest volcano in the world; it is also the highest mountain in Spain and the focus of the most heavily visited national park in Europe. In 2007 this ocean island achieved UNESCO World Heritage Site status for the diversity of volcanic island processes shown. That well-displayed diversity is why I have taken groups of OUGS members there regularly since 1997 and why, for me, this book was a 'must read'.

Teide has a long-term role in geology's development: it supplied evidence that helped 'plutonists' to win their argument with the 'neptunists'. Despite this, very little material was available for early OUGS visits; but the amount of published research has increased remarkably since, due especially to Teide's status as a 'Decade Volcano' of the IAVCEI's 'International decade for disaster reduction'. Initially the research triggered was extremely helpful: it made increasingly fascinating reading as more and more became known about the volcano. But the annual task of updating my notes eventually became almost overwhelming, so that this book — the first in English summarising Teide's geology and associated hazards — is particularly welcome for me. I'm sure it will be equally welcome to other geologists, amateur and professional, who visit Tenerife.

The book is well illustrated with numerous colour images and is comprehensive in nature: an introductory section details historic study of Teide and then the book looks at wide ranging aspects: geological setting, geomorphology and structure, and discusses in detail the Northeast rift zone and dating methods. It describes the last 2,000 years of Teide's volcanic history, and looks at the island's petrology: magma differentiation and magma mixing, before moving on to eruption styles and recent geophysics. The book concludes with the major driver for contemporary research: volcanic hazards and the associated risks and mitigation methods.

There is a full reference list for each chapter, a comprehensive index and biographies of the chapter authors. It is available both in hardcover (£90) and an eBook (£72), and the latter will be the version I have on my tablet for quick reference when I take the next OUGS group to Tenerife in April 2014.

— Linda Fowler, BA (Hons, Open), OUGS Chairman

Book review

Vita-Finzi, Claudio, and Fortes, Dominic 2013 *Planetary Geology* (2nd edn). Edinburgh: Dunedin Press (ISBN 978-1-78046-015-4; paperback, 189pp; £25)

This is a very remarkable book, for at least three reasons. First, that so much should now be known about the eight major planets, five dwarf planets, and 179 satellites (to use the terminology which was decreed by the International Astronomical Union in 2006). Second, that so many of the facts known or hypothesized about many of these extra-terrestrial bodies should prove to have resemblances to the geology of Earth. Third, that the authors should have laid out such an array of material so succinctly and with such excellent illustrations, a high proportion of them in colour.

It is only just over 400 years since Galileo's first observations of the largest moons of Jupiter, only 100 years since the detection of an atmosphere on Titan, the largest satellite of Saturn, only 50 years since the landings on the Moon — still the only planetary body directly observed by humans standing on its surface. Yet now, to give examples at random, we can make intelligent accounts comparing the interiors of the four gas giant planets; or of the not dissimilar Ganymede and Europa, different from the trio of Titan, Triton and Pluto, which have a resemblance, and are different again from less differentiated Callisto. We can ponder the magnetic dichotomy of Mars. We have evidence that volcanism on Mercury persisted until "as recently as 1Gyr ago", and that Venus has 145 pancake domes 10–100km in diameter and up to 4,500m high.

Whether dealing with impacts or tectonics, oceans and ice caps, topography and gravity, examples from Earth are put alongside ones from other bodies, and cannot but make the reader think of the geological features of our planet in a different perspective.

The language used by the authors (currently Londoners, the first from the Natural History Museum, the second from Birkbeck and University Colleges) is extremely clear, like their figures, photographs and diagrams. The five-page glossary is useful if one is becoming confused. Although there are no footnotes or references in the text, the eight pages of references to articles look easy to use. At the price, and not weighing too much to handle, I can imagine members of our society wanting to buy this comprehensive work.

— Philip Clark, MA (Oxon), BSc (Open)

The zeolite minerals (part 2)

Oneta Wilson (OUGS NW), Alan Dyer (OUGS NW, aldilp@aol.com) and David Green

Introduction

This is the second of two articles on zeolites. It deals with the more commonly occurring zeolites in Great Britain. Included are methods of identification, descriptions of individual zeolites, with photographs, and information on localities where these zeolites can be found. (Diagrams after Tschernich 1992, with permission; photographs by David Green.)

Methods of identification

In the field the majority of zeolite crystals are colourless, although at some localities in the British Isles they can be red, pink, orange, brown or yellow.

The crystals can be large — but can also be small, and this can make identification difficult, particularly as they frequently occur with calcite or quartz. In some cases species, such as chabazite and thomsonite, can grow together in the same cavity. This is common on the Isle of Skye.

Dilute hydrochloric acid (HCl) can be used to differentiate zeolites from calcite, which will effervesce if a dropper bottle is used to drop the acid on to it. Zeolites can be distinguished from quartz as they are much softer when scratched with a penknife.

Most mineral collectors find access to a good microscope invaluable and zeolite collectors are no exception. Apart from the pleasure gained from observation of their beauty, zeolites have distinctive crystalline habits that enable their identity to be confirmed by microscope study. This is illustrated later for individual examples.

As with many other minerals, more sophisticated techniques are needed for the identification of some specimens. The main technique for zeolites is X-ray powder diffraction, and use of a modern diffractometer can also give access to a computer search program specifically tailored to identify zeolite powder patterns. Thermal, infrared and electron microscopy analyses are also useful and a full elemental analysis is always advisable. Members of the British Museum staff are very helpful in the provision of identification of samples not readily confirmed by optical microscopy.

Zeolites found in the British Isles

The finest and most varied zeolites are found in the Tertiary basalts, mostly in lavas, of Scotland (Midland Valley, Hebridean Islands) and in Northern Ireland. Some of them represent type localities and are world famous.

The more commonly found zeolites are here described, with several photographs to illustrate the beauty of their crystalline habits. Note that the colours and types of genesis refer to their worldwide occurrences. The 'other localities' cited are not meant to be comprehensive, but to suggest localities where collection is relatively easy — but may still need landowner's permission.

A comprehensive list of localities is in Wilson, Dyer and Enamy 2003.

Analcime ANA (Diag. 1; Fig. 1)

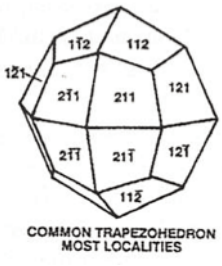
Na $[Al_2SiO_6]$. H_2O

Series: Analcime shares a framework structure (see Wilson and Dyer 2012) with the other zeolites pollucite, wairakite and leucite.

Crystal system: isometric, tetragonal, orthorhombic, monoclinic, triclinic

Habit or form: Usually analcime is in the form of icositetrahedral crystals with small cube faces present in the dominant trapezohedron. Other forms are very rare.

Diagram 1 Analcime



Colour: Invariably white/colourless in the British Isles, but pink, red and green crystals have been found.

Genesis: Crystallises in many environments, including hydrothermal solutions in volcanic rocks, low-grade metamorphosed volcanics, pegmatites, phonolites and pyroclastic rocks.

First record in British Isles: Dumbarton, Haüy (1801)

Other localities: Dean Quarry, St. Keverne, Cornwall; Croft Quarry, Leics.; Glenarm, Co. Antrim; Ross Strand, Killala Bay, Co. Mayo; Talisker Bay, Isle of Skye; Carsaig Bay, Isle of Mull

Figure 1 Analcime: Croft Quarry, Croft, Narborough, Leics.

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Brewsterite BRE (Diag. 2; Fig. 2)

$(Sr,Ba)_2$ $[Al_4Si1_2O_{32}]$. $10H_2O$

Series: Brewsterite-Sr, Brewsterite-Ba

Crystal system: triclinic

Habit or form: blocky to prismatic crystals, pseudo-monoclinic in form

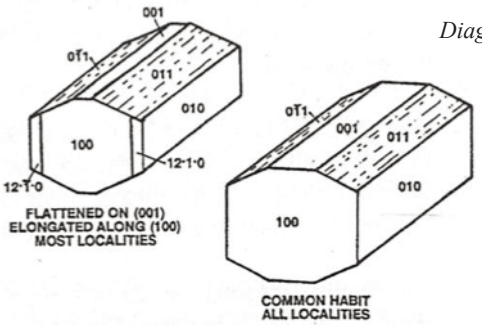


Diagram 2 Brewsterite

Colour: colourless to white, pink, yellow, brown

Genesis: In hydrothermal veins crossing numerous rock types, such as metamorphic gneiss and schists, plutonic syenites, limestones and volcanics; also as a late stage primary mineral in ore deposits.

First record in British Isles, and **Type Locality:** Strontian, Argyll, Brooke (1822)

Figure 2 Brewsterite: Whitesmith Mine, Strontian, Argyll, Scotland.

Chabazite CHA (Diag. 3; Fig. 3)

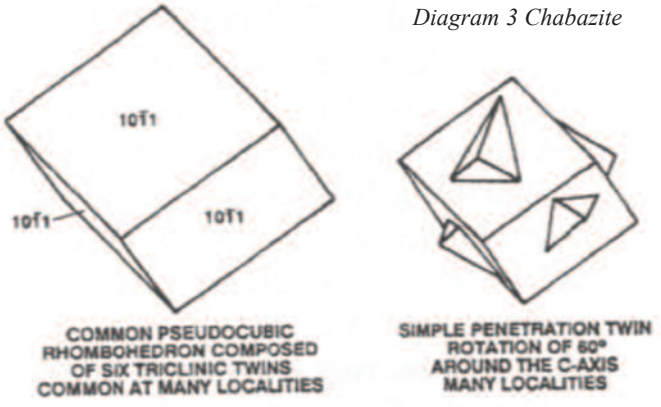
$(Ca_{0.5},Na,K)_4$ $[Al_4Si_8O_{24}]$. $12H_20$

Series: Chabazite-Ca, Chabazite-Na (formerly known as herschelite)

Crystal system: triclinic (pseudo-hexagonal), trigonal.

Habit or form: Distorted cube or pseudo-orhombohedron, commonly as twin crystals often seen as penetrating twins (*see below*).

Diagram 3 Chabazite



Colour: colourless, white, yellow, red, green and brown

Genesis: Common in most volcanic rocks, altered volcanic ash deposits — in both fresh and saline lakes — pegmatites, granite and metamorphic rocks. In the British Isles it most commonly occurs in Tertiary basalts.

First record in British Isles: Talisker Bay, Isle of Skye, also at Glenfarg (Perthshire), Portrush Co. Antrim, Phillips (1819)

Other localities: Dean Quarry, St. Keverne, Cornwall; Ramsley Mine, Sticklepath, Devon; Coatgate Quarry, Dumfries and Galloway; Oisgill Bay, Isle of Skye; Carsaig Bay, Isle of Mull

Figure 3 Chabazite: Talisker Bay, Minginish, Isle of Skye, Scotland.

Harmotome HAR (Diag. 4; Fig. 4)

$(Ba_{0.5},Ca_{0.5},K,Na)_5$ $[Al_2Si_{11}O_{32}]$. $12H_2O$

Series: Harmotome forms a continuous series with phillipsite-Ca.

Crystal system: monoclinic (pseudo-orthorhombic), triclinic

Habit or form: Occurs as pseudo-orthorhombic twinned prismatic crystals. Twinning is complex (see diagrams below) and its morphology is identical to that of phillipsite.

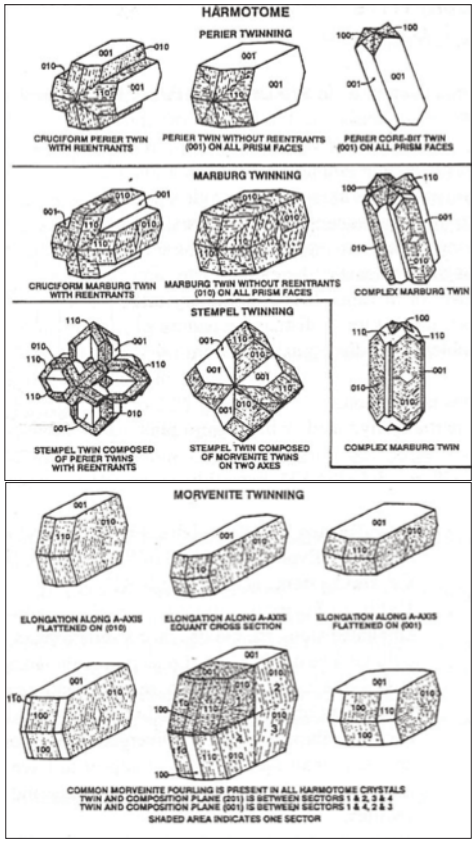

HARMOTOME
PERIER TWINNING
CRUCIFORM PERIER TWIN WITH REENTRANTS
PERIER TWIN WITHOUT REENTRANTS (001) ON ALL PRISM FACES
PERIER CORE-BIT TWIN (001) ON ALL PRISM FACES
MARBURG TWINNING
CRUCIFORM MARBURG TWIN WITH REENTRANTS
MARBURG TWIN WITHOUT REENTRANTS (010) ON ALL PRISM FACES
COMPLEX MARBURG TWIN
STEMPEL TWINNING
STEMPEL TWIN COMPOSED OF PERIER TWINS WITH REENTRANTS
STEMPEL TWIN COMPOSED OF MORVENITE TWINS ON TWO AXES
COMPLEX MARBURG TWIN
MORVENITE TWINNING
ELONGATION ALONG A-AXIS FLATTENED ON (010)
ELONGATION ALONG A-AXIS EQUANT CROSS SECTION
ELONGATION ALONG A-AXIS FLATTENED ON (001)
COMMON MORVENITE POURLING IS PRESENT IN ALL HARMOTOME CRYSTALS
TWIN AND COMPOSITION PLANE (201) IS BETWEEN SECTORS 1 & 2, 3 & 4
TWIN AND COMPOSITION PLANE (001) IS BETWEEN SECTORS 1 & 4, 2 & 3
SHADED AREA INDICATES ONE SECTOR

Diagram 4 Harmotome

Colour: colourless, white, grey, red, yellow, orange, brown

Genesis: Most of the major occurrences are in late stage hydrothermal lead and lead-silver ore veins. In volcanics it is commonly caused by hydrothermal alteration of barium minerals. It is rare in altered tuff deposits.

First record in British Isles: Strontian, Argyll, by Phillips (1819)

Other localities: Brownley Hill Mine, Nenthead, Cumbria; Squilver Quarry, Shropshire; Cwm Orog Mine, Powys; Dolyhir Quarry, Powys; Conlig Mine, Newtownards, Co. Down

Figure 4 Harmotome, Dolyhir Quarry, Old Radnor, Powys, Wales.

Heulandite HEU (Diag. 5; Fig. 5)

$(Ca_{0.5},Sr_{0.5},Ba_{0.5},Mg_{0.5},Na,K)_9$ $[Al_9Si_{27}O7_2]$. *c.* $24H_2O$

Series: Heulandite-Ca, Heulandite-Sr, Heulandite-Na, Heulandite-K

Crystal system: monoclinic

Habit or form: Platey, trapeziodal crystals with a dominant pinacoid parallel to an excellent cleavage and with one or two sets of triangular faces. Crystals are
commonly referred to as 'coffin-shaped' and have a characteristic pearly lustre.

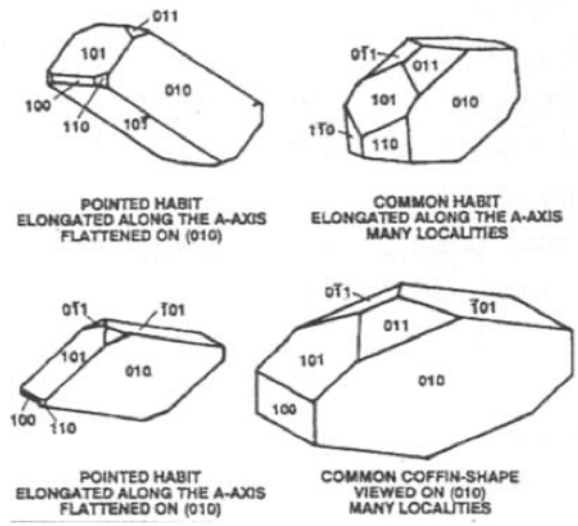

POINTED HABIT ELONGATED ALONG THE A-AXIS FLATTENED ON (010)
COMMON HABIT ELONGATED ALONG THE A-AXIS MANY LOCALITIES
POINTED HABIT ELONGATED ALONG THE A-AXIS FLATTENED ON (010)
COMMON COFFIN-SHAPE VIEWED ON (010) MANY LOCALITIES

Diagram 5 Heulandite

Colour: colourless, white, yellow, pink, red, brown, green, black

Genesis: Found in volcanic and metamorphic rocks, pegmatites; in the British Isles principally in Tertiary basalts and the Carboniferous age basaltic andesite lavas of the Midland Valley of Scotland.

First record in British Isles: near Dumbarton and on the Isle of Skye, Brooke (1852)

Other localities: Whitesmith Mine, Strontian, Argyll; Touch Muir, Stirling; Todhead Point, Kincardineshire; Wheal Hazard, Botallack, Cornwall; Callow Hill Quarry, Minsterley, Shropshire; Garron Plateau, Co. Antrim

Figure 5 Heulandite, Whitesmith Mine, Strontian, Argyll, Scotland.

Laumontite LAU (Diag. 6)

Ca_4 $[Al_8Si_{16}O_{48}]$. $18H_2O$
Crystal system: monoclinic
Habit or form: Distinctive single prisms of square cross-section, elongated along the c-axis. It is alone in the zeolite minerals in that it readily dries out and crumbles to a less hydrated form previously known as 'leonhardite', but discredited as a distinct mineral species.

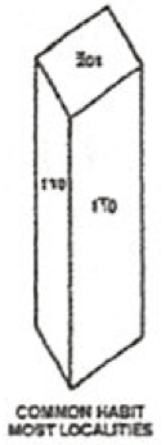


Diagram 6 Laumontite

Colour: colourless, white, pink
Genesis: Widely found in many geological conditions. These include hydrothermal solutions in ore deposits, volcanic rocks, pegmatites, intrusive rocks, hot springs, as weathering of plagioclase, as natural cements in sandstones, in the alteration of volcanic ash in saline lakes and in deep-sea sediments.
First record in British Isles: Phillips (1819) described laumontite near Paisley, Renfrew, near Loch Eynort on Skye, and at Portrush, Co. Antrim.
Other localities: Lochaline, Morven, Sunart Peninsula, W. Scotland; Tobermory to Glengorm Rd, Isle of Mull; Dockray, Ullswater, Cumbria; Moons Hill Quarry, Shepton Mallet, Somerset; Llanelwedd Quarry, Builth Wells, Powys

Levyne LEV (Diag. 7)

$(Ca_{0.5},Na,K)_6$ $[Al_6Si_{12}O_{36}]$. *c.* $17H_2O$
Series: Levyne-Ca, Levyne-Na
Crystal system: trigonal
Habit or form: thin tabular plates, usually twinned

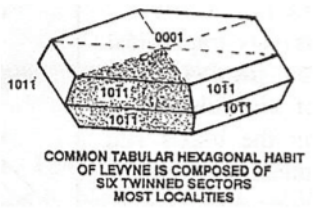


Diagram 7 Levyne

Colour: colourless, white, grey, yellow, red
Genesis: Always hydrothermal. Found in olivine basalt and rarely in andesite. In the British Isles it is found in Tertiary basalts.
First record in British Isles: Probably Storr, Isle of Skye by Connell (1834)
Other localities: Oisgill Bay, Duirnish and Talisker Bay, Isle of Skye; Glenarm and Glenarriff Valley, Co. Antrim

Mesolite NAT (Fig. 6)

$Na_{16}Ca_{16}$ $[Al_{48}Si_{72}O_{240}]$. $64H_2O$
Crystal system: Orthorhombic
Habit or form: Long, slender, acicular crystals, not easily distinguished from natrolite and scolecite — they share the same framework structure and hence the same three-letter code. Found as sprays of crystals or as hair-like mats known as 'cotton stone'. Mesolite is often seen as radiating from thomsonite hemispheres and supporting crystals of chabazite, analcime or calcite at the centre of vugs.
Colour: colourless, white, pink, red, green
Genesis: Common in basalts; in the British Isles common in Carboniferous and Tertiary basalts.
First record in British Isles: By Heddle (1856) at Storr, Isle of Skye
Other localities: Isle of Skye (numerous); Isles of Ulva and Mull; Garron Plateau, Co. Antrim

Figure 6 Mesolite, Sgurr nan Boc, Minginish, Isle of Skye, Scotland.

Figure 7 Natrolite, Dean Quarry, St. Keverne, Cornwall.

Natrolite NAT (Diag. 8; Fig. 7, *previous page*)

Na_{16} $[Al_{16}Si_{24}O_{80}]$. $16H_2O$

Crystal system: orthorhombic

Habit or form: long thin needles and coarse prismatic crystals, square in cross section

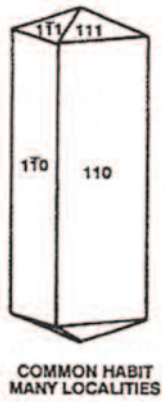


Diagram 8 Natrolite

Colour: colourless, white, yellow, grey, red, green, brown

Genesis: Found in silica — poor basalts, nepheline syenite complexes, pegamatites, marine pillow lavas and breccias. Often facilitated by presence of seawater or saline lake waters during zeolitisation, rather than meteoric water.

First record in British Isles: Phillips (1819) Isles of Skye and Mull

Other localities: Thurstaston, Wirral, Cheshire (in erratics from the Ice-age); Dean Quarry, St. Keverne, Cornwall; Calton Hill Quarry, Buxton, Derbyshire; Brown's Bay, Isle Magee, Co. Antrim; Bunnahabhain, Isle of Islay; Canty Bay, East Lothian; Ruddon's Point, Fife; Hartfield Moss, East Renfrewshire; Edinbane, Isle of Skye; Ardnacross, Isle of Mull; Benallt Mine, Rhiw, Gwynedd; Glenfarg, Perthshire

(See Figure 7 on previous page.)

Scolecite NAT

Ca $[Al_2Si_3O_{10}]$. $3H_2O$

Crystal system: orthorhombic

Habit or form: thin prismatic crystals, often flattened and twinned

Colour: colourless, white, pink, salmon, green, red

Genesis: Occurs in basalt, gneiss and in contact metamorphic zones. In the British Isles, found mainly in the Tertiary basalts of the Isle of Mull.

First record in the British Isles: in 'needlestone' on the Isle of Staffa (Brooke (1820)

Other localities: Ben More, Isle of Mull; Ard Fernal, Isle of Jura; Sgurr an Duine, Loch Eynort, Isle of Skye; Henscarth, Mullion Cove, Cornwall; Dunseverick, Co. Antrim

Stilbite STI (Diag. 9; Fig. 8)

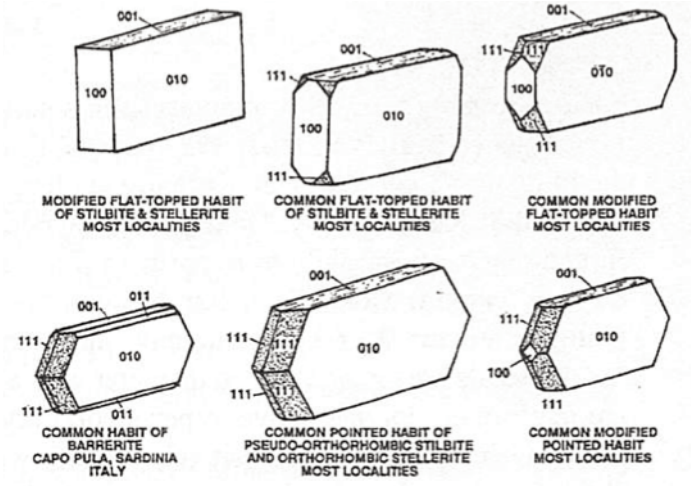
$(Ca_{0.5},Na,K)_9$ $[Al_9Si_{27}O_{72}]$. $28H_2O$

Series: Stilbite-Ca, Stilbite-Na, (**Stellerite** is a Ca-rich zeolite similar to stilbite in framework and habit, and shares the same three letter code).

Crystal system: monoclinic, pseudo-orthorhombic

Habit or form: Tabular crystals, flattened to the dominant cleavage. Well known as radiating sheaves of crystal, including bow tie and spherical aggregates, always twinned. Stellerite has a very similar habit but can often be distinguished from stilbite by its pearly lustrous surfaces.

Diagram 9 Stilbite


001
010
100
MODIFIED FLAT-TOPPED HABIT OF STILBITE & STELLERITE MOST LOCALITIES
111
COMMON FLAT-TOPPED HABIT OF STILBITE & STELLERITE MOST LOCALITIES
0$\bar{1}$0
COMMON MODIFIED FLAT-TOPPED HABIT MOST LOCALITIES
011
COMMON HABIT OF BARRERITE CAPO PULA, SARDINIA ITALY
COMMON POINTED HABIT OF PSEUDO-ORTHORHOMBIC STILBITE AND ORTHORHOMBIC STELLERITE MOST LOCALITIES
COMMON MODIFIED POINTED HABIT MOST LOCALITIES

Colour: colourless, white, yellow, red, pink, salmon, green, blue, black, brown

Genesis: Very common throughout the world in volcanic rocks, pegmatites, metamorphic gneiss and schists. The largest crystals are found in tholeiite basalts.

First record in the British Isles: Stilbite — Old Kirkpatrick, Dumbarton by Brooke (1820); **Stellerite** —Slieve-na-Gravery, Belfast by Doherty (1983)

Other localites: Stilbite — Dean Quarry, St. Keverne, Cornwall; Dunseverick, Co. Antrim; Todhead Point, Kincardineshire; Lang Craigs, Dumbarton; Dunvegan Quarry, Dunvegan, Isle of Skye; Frachadil, Isle of Mull; Isle of Ulva; Thundergay Beach, Isle of Arran; Hushinish, Harris, Outer Hebrides; **Stellerite** — Edinbane, Isle of Skye; Bradon Bay, Kincardineshire; Tardee Forest Quarry, Co. Antrim

Figure 8 Stilbite, Moonen Bay, Duirnish, Isle of Skye, Scotland.

Thomsonite THO

$Ca_2Na\ [Al_5Si_5O_{20}].\ 6H_2O$
Crystal system: orthorhombic
Habit or form: Occurs in a wide range of habits — common as thin rectangular blades, blocky prismatic crystals, long acicular crystals. Compact small spheres of characteristic blue-white colouration are also known.
Colour: Colourless, white, pink, red, orange, yellow, green, blue
Genesis: Common in low-silica basalts, less so in pegamitites, contact metamorphic zones, and silica-rich tholeiitic basalts.
First record in British Isles: Old Kilpatrick, Dumbarton by Brooke (1820)
Other localities: Thurstaston erratics, Wirral; Ross Strand, Killala Bay, Co. Mayo; Dunseverick, Co. Antrim; Bruslee, Ballyclare, Co. Antrim; Flodigarry, Trotternish, Isle of Skye; Kingsburgh Quarry, Trotternish, Isle of Skye; Bunnahabhain, Isle of Islay; Glen Court, Usk, Gwent

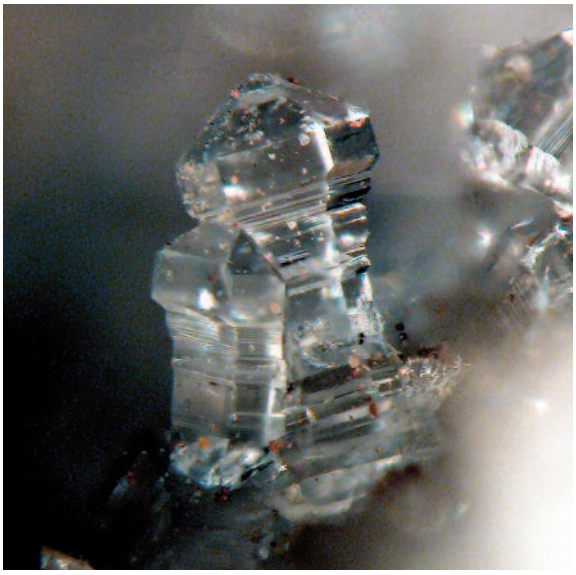
Other zeolites

Other zeolites that have been reported in the British Isles (Tschernich 1992; Wilson, Dyer and Enamy 2003):

Clinoptilolite Wheal Hazard, St. Just, Cornwall (Fig. 9)
Cowlesite Dunseverick, Co. Antrim
Edingtonite Old Kilpatrick, Dumbarton
Epistilbite Talisker Bay, Isle of Skye
Erionite Catcairn Quarry, Co. Antrim
Faujasite possibly present at Storr, Isle of Skye
Ferrierite Burntisland, Fife
Garronite Garron Plateau, Co. Antrim
Gismondine Oisgill Bay, Isle of Skye
Gmelinite Little Deer Park, Glenarm, Co. Antrim (Fig. 10)
Gobbinsite Isle Magee, Gobbins, Co. Antrim
Mordenite Todhead Point, Kincardineshire
Offretite Catcairn Quarry, Co. Antrim
Paulingite Lacada Point, Giant's Causeway, Co. Antrim
Phillipsite Oisgill Bay, Isle of Skye
Wairakite Midland Valley, Scotland

Figure 9 (below) Clinoptilolite, Wheal Hazard, Botallack, St. Just, Cornwall.

Figure 10 (right) Gmelinite, Magheramorne Quarry, near Larne, Co. Antrim, N. Ireland.



Collecting

It is hoped that this article will encourage readers to collect zeolites — and other minerals! There are two organisations that can help and advise collectors:

(i) The Russell Society, a society of amateur and professional mineralogists that encourages the study, recording and conservation of mineral sites and material — www.russellsoc.org
(ii) British Micromount Society. The aims of the Society are to promote contact between micromounters in the U.K. and encourage the development of micromounting as a branch of mineralogy. The Society publishes the British Directory of Micromounters — now in its 10th edition, and maintains a National Reference Collection of micromounts, available for postal loan to members. The Society has also developed a range of Occasional Papers on topics of interest to amateur mineralogists:
http://britishmicromountsociety.homestead.com/

Both organisations have local branches, which welcome newcomers, organise lectures and field trips (some abroad), publish regular newsletters and hold annual symposia. The Russell Society also publishes a peer-reviewed journal.
If you intend to collect then the Natural England website:

http://www.naturalengland.org.uk/

carries advice on the right way to go about both mineral, and fossil, collecting (enter 'collecting' into the 'search' option).

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References

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